From the Andes to the Coast: Human Mobility and Diet in the Atacama Desert during the Late Intermediate Period (AD 900-1450)



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Trinity Term 2016

A Thesis presented for the University of Oxford in partial fulfilment of the requirements for the Degree of Doctor of Philosophy

To Meme and Tante

“Mírame desde el fondo de la tierra,
labrador, tejedor, pastor callado
domador de guanacos tutelares
albañil del andamio desafiado
aguador de las lágrimas andinas
joyero de los dedos machacados
agricultor temblando en la semilla:
alfarero en tu greda derramado […]
Yo vengo a hablar por vuestra boca muerta
A través de la tierra juntad todos
los silenciosos labios derramados
y desde el fondo habladme toda esta larga noche
como si yo estuviera con vosotros anclado”
Pablo Neruda, Alturas de Machu Picchu, Canto General

Preface

This thesis brings together the research I started in 2009 during my undergrad studies in Santiago de Chile until today. I became interested in the Late Intermediate Period (LIP) in northern Chile due to its particular features, especially on the absence of empires or state during these moments. I was (and still am) particularly interested on how the human groups that lived in the driest desert in the world, managed to use the environment and generate contacts between them, across different geographical regions. Based on the results I obtained from isotope analysis carried out for my undergrad and masters thesis on the diet and mobility patterns of individuals from Quillagua, Pica and San Pedro de Atacama, I started questioning the mobility models proposed for the area. Because the LIP is chronologically close to the Inka and Spanish conquerors arrival, most of the ethnohistorical documents and theories proposed for those late times have been applied directly to the past. From the evidence obtained in my previous research, questions raised on the application of the ethnohistorical and archaeological models of mobility for the LIP, since these were not enough to explain the mobility patterns observed from the isotope results. For this reason, I expanded my research on the LIP, previously focused on inland cemeteries, to sites in the coast and highlands in order to better evaluate the mobility and diet during the LIP, aiming to test the classical models. In addition, by the time (2009) I started working on stable isotope analysis in northern Chile, this subject did not have the popularity that it has now, with the exception of the works carried out by Kelly Knudson on strontium isotopes in San Pedro de Atacama. By then there was an absolute lack of information regarding archaeological plants and animals. No isotope baselines were available with the exception of the one published for modern flora and fauna by Tieszen and Chapman (1992) for the Arica coast, valleys and *puna* (highlands). However, Arica is more than 600 km away from my study area (Tarapacá and Atacama Oases) and the isotope compositions of plants and animals might present variations. In contrast to Arica, the Tarapacá region is absolutely endorheic and water sources are scarce, being the arid conditions even more extreme. For this reason, I also

decided to develop a new isotope baseline for modern and archaeological plants and animals in order to better understand the dietary patterns in the local populations. A similar situation occurred with the construction of a bioavailable strontium map for northern Chile. I decided to carry out this research due to the lack of information of these topics for northern Chile.

This thesis will present the results obtained during four years of work that included two fieldwork seasons in Chile for collecting samples, sample analysis in different laboratories of the UK and South Africa, as well as statistical analysis.

The development of this research would not have been possible without the support, encouragement and help of my two supervisors Julia Lee-Thorp and Rick Schulting. I would like to express my deepest gratitude to them, for the immense knowledge, generous guidance, motivation, understanding and patience. I consider myself lucky and thankful for having the chance of meeting them and the opportunity to work together.

I am thoroughly grateful to Julie Hamilton, Peter Ditchfield and Dave Peat for their kind help and guidance during these last five years (including my master's year) in the diet lab, where they taught me all the analytical procedures necessaries for carrying on my research.

I am deeply thankful to everyone in the Oxford Radiocarbon Accelerator Unit for teaching me how to proceed in the lab and on the use of the machines. I thank Tom, Dave, Dan, Kathryn, Jane, Angela, and Barbara for their kindness and happy moments in the lab.

I would also like to thank my friends in the RLAHA, Diane, Joe, Mike, Thibaut, Marine, Scott Paul, Richard, for all their support and help in the good and bad moments.

I would like to express my very profound gratitude to Mauricio Uribe for introducing me to northern Chile's prehistory, and for teaching me to always be critic on how we interpret the past.

Special thanks to Rodrigo Retamal and Pablo Méndez-Quiros, whom I consider my brothers, for all the support given during the last 8 years, for teaching me bioanthropology and archaeology, and also for helping me collecting the samples for my DPhil research.

I would also like to acknowledge Mark Hubbe for always encouraging me to follow and academic career (including coming to study abroad) and never give up.

I would like to thank the Strontium isotope Chilean-South African-New Zealand team, including Petrus, Kerryn, Benigno, Osvaldo and Andrew for all their help, including the invitation to fieldwork in the Andes for collecting samples, and their knowledge on geology.

My sincere thanks to all the institutions that allowed me access to their collections in order to take archaeological and bioanthropological samples including the Instituto de Investigaciones Arqueológicas (San Pedro de Atacama), Museo Regional de Iquique, Museo de Antofagasta, Museo Nacional de Historia Natural and Universidad de Chile. I would also like to thank Virginia Mcrostie for her help with the plant samples.

I would like to express my sincere gratitude to my DPhil-friends Christophe, Amy, Michaela, Petra, Laura, Eduardo and Emma for the good times in Oxford, as well for their support and care.

Special thanks to my Chilean friends in Oxford, Tamara, Nicolito-El Salvador, Nicolas, Lorena, Magdalena and Simón for their help with stats (R), plant physiology, Arc GIS and of course for all their wonderful friendship and company.

I would like to express my sincere gratitude to my family, for believing and me and supporting since the very beginning, especially to my mum Alejandra and my brother Sebastián, for all their help during my DPhil with the posting of samples and editing of figures.

I would also like to thank my friends Coni, Leila, Umberto, François and Pallavi for always been there when I have needed support and help.

Finally I would like to thank Alexis S. for making my days in the UK much happier, despite the bad weather and the deficit in vitamin D, and for demonstrating us that nothing in life is impossible (CBC).

Abstract

The Late Intermediate Period in northern Chile has been strongly influenced by the mobility models of vertical archipelago and the gyratory mobility. The vertical archipelago model proposes *altiplano* colonies would have lived in the lowlands controlling trade and distributing economic resources. The gyratory mobility suggests trade was rather controlled by pastoralist groups from the highlands, travelling across the Andes using llama caravans. Following new studies on stable isotope analysis for the LIP in the Atacama Desert, there is little evidence to support the colonies hypothesis. For this reason, the aim of this thesis is to evaluate the presence of colonies and specialised highland pastoralist groups in the lowlands of northern Chile through the use of $\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ as well as radiocarbon dating. Human remains were analysed for tooth enamel, bone collagen, bone apatite, and hair-keratin. A second aim of the thesis was to provide new analysis of archaeological plants and animals of the area. Plants results present incredibly high $\delta^{15}N$ values for the crops, suggesting use of fertilisers on them, probably seabird guano from the coast. This is also supported by the absence of a marine reservoir effect on the radiocarbon dates, reflected in the lack of offset between paired dates of bone collagen and textiles in individuals enriched in ^{15}N. The results obtained for the human remains suggest there is no evidence to support neither the 'colony' hypothesis nor the gyratory mobility model. However, a small number of outlier individuals for $\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ suggest a non-local origin. Mobility patterns were diverse and flexible including female and male individuals that moved at different moments of their life (infancy and adulthood). This study shows that dietary patterns in the Atacama Desert during the LIP were associated with strong local traditions.

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are marked with an asterisk (*). Burial offering information was obtained from Costa-Junqueira (1988) for Quitor 6, Zlatar (1984) for Pica 8 and Agüero et al. (1999) for Quillagua. Sector information was included for the Pica 8 individuals below their inventory numbers.

Chapter 1

Introduction

1.1 The archaeology of the Late Intermediate Period in the Atacama Desert: The classical mobility models revisited

During pre-Columbine times the South Central Andes experience many cultural developments, including the emergence, expansion and decline of states and empires such as Tiwanaku (AD 400-1000) and the Inka (Fig 1.1) (Berenguer and Dauelsberg, 1989; Schippacasse et al., 1989). However, inbetween these empires there was a period characterised by complete absence of centralised states, known as the Late Intermediate Period (LIP) (AD 900-1450), which witnessed the appearance of culturally independent societies occupying the region from the Andes to the coast. Contact and trade between ecological regions were frequent, leading to suggestions that people, too, were highly mobile. Several models have been proposed to understand the nature of interactions between the people from highlands and lowlands.

Most of the models are based in some way on the regional Andean geography. In northern Chile as well as in Peru, the different ecological zones follow an altitudinal gradient with specific types of resources and geographical features. Northern Chile is characterised by the extremely dry Atacama Desert dominating most of the landscape. At least four different ecological zones (Troll, 1958) can be identified here including the coast, the valleys (also known as *pampa*), the pre-cordillera and highlands (Figure 1.1). Despite the hyperaridity, different populations managed to inhabit all these ecological zones in northern Chile.

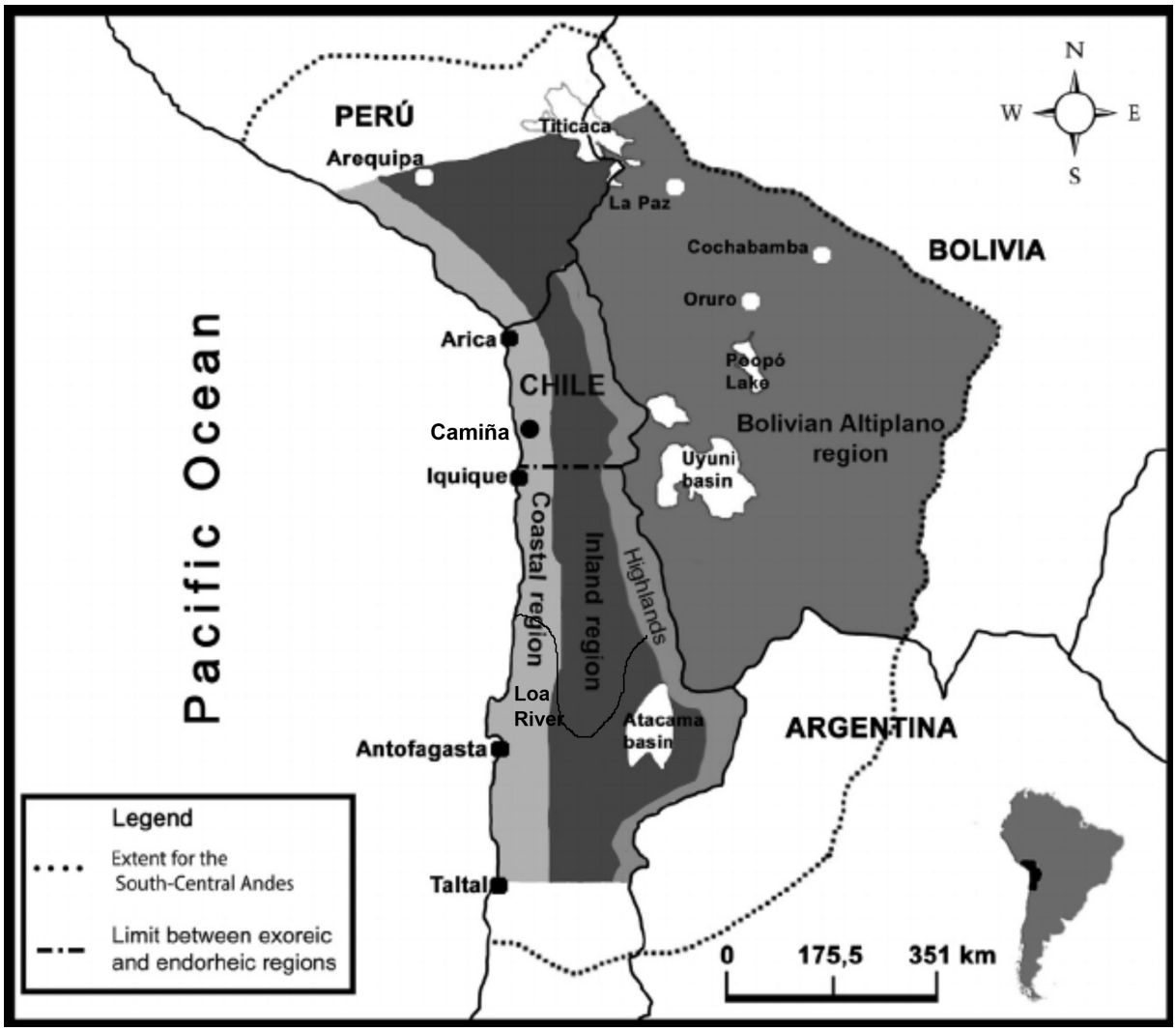


Figure 1.1. South Central Andes Map (modified from Gayo et al., 2015). Ecological zone division for northern Chile is presented in scale of grey including the coastal, inland and highlands regions.

The main mobility hypothesis for this period is based on ethnohistorical research by John Murra in the 1970s (Murra, 1972). Following the particular geography of the Andean region, Murra (1972) proposed the vertical archipelago model in which groups from the different ecological zones (mountains, valleys and coast) would complement each other by the exchange of local resources. This model proposes the imposition of *altiplano* colonies in the lowland territories. Here, the *altiplano* colonies controlled the trade of resources (Murra, 1972). Most of the evidence found in sites dated to the LIP in the South Central Andes has been interpreted following this theoretical model, and assuming the presence of *altiplano* people.

Núñez and Dillehay (1995) have taken this further, proposing a model of 'gyratory mobility' for the South Central Andes, in which mobility between the colonies or local groups was controlled by specialised agro-pastoralist groups, coming from the highlands and/or *altipano*. These groups moved along the altitudinal gradient using llama caravans. The movements would have occurred between sites in the *altiplano*; *altiplano*-valleys; *altiplano*-coast; valleys-coast. Hence, the *caravaneros* would exchange the complementary resources in each ecological zone.

These two main models have deeply influenced the archaeological interpretations of the LIP, especially in northern Chile (Núñez, 1984; Schiappacasse et al., 1989; Moragas, 1995; Santoro et al., 2003; Santoro et al., 2004; Uribe, 2006). They have relied on artefactual evidence, such as the presence of textiles, specific pottery types from the Andes (i.e. Hedionda and Chilpe types), flamingo feathers, obsidian instruments, *quinoa* and *chuño* (potato flour) that occur in lowland sites (Núñez, 1984; Schiappacasse et al., 1989; Santoro et al., 2003; Santoro et al., 2004). In this sense, the *altiplano* evidence has been assumed to be a clear reflection of the colonies presence in the lowlands (Núñez, 1984; Schiappacasse et al., 1989; Santoro et al., 2003). However, the frequency of this *altiplano* evidence is low in most of northern Chile sites. In contrast, there is a strong, clearly local component in all the sites dating to the LIP in the Atacama Desert (Uribe et al., 2004; Uribe, 2006).

The use and application of these two models for the local archaeological evidence of northern Chile is then problematic. First of all, there is not enough material evidence to support the presence of colonies, questioning the vertical archipelago model (Murra, 1972). Secondly, if *altiplano* objects appear in the archaeological record it does not necessarily mean people were actually living there. For instance, these objects could be a result of long distance trade. In this sense, the gyratory mobility model (Núñez and Dillehay, 1995) could better explain the presence of foreign objects in the local sites. However, it is possible that human mobility was not only reduced to a group of specialised pastoralist groups coming from the highlands/*altiplano* to the lowlands. Furthermore, this model does not explain

whether these groups were part of a particular society or cultural group, and who were the people that belonged to the groups. For instance were they adults, both males and females, or families?

Ethnohistorical reseach carried out in northern Chile, southern Bolivia and north-west Argentina showed that individuals moved from and to all these different regions in order to establish kin relationships, political connections and the use of local resources such as lands for agriculture and pastoralism (Martínez, 1998). Thus, Martínez (1998) proposed that mobility was rather flexible and did not follow strict rules associated with geographical locations or ethnic associations from the XVI to the XVIII centuries. It is possible that a similar situation could have happened for the LIP.

New archaeological research based on isotopic analysis in ancient human samples from northern Chile, dating to the LIP has shown also a strong local component in the cemeteries, with some individuals indicating a non-local origin (Santana-Sagredo et al., 2015a; Santana-Sagredo et al., 2015b). The foreign individuals are rather diverse in their diet composition and possible place of origins, questioning the hypothesis of colonial enclaves in the Atacama Desert.

Even though the archaeological evidence clearly shows a local component in the area, the vertical archipelago and the gyratory mobility maintain a strong influence on the archaeological interpretations of northern Chile until today (Santoro et al., 2003; Berenguer, 2004; Pimentel, 2012). Following the absence of archaeological evidence supporting these models, this thesis sets out to evaluate human mobility during the LIP in three cultural areas of northern Chile through a multi-isotopic approach.

The three cultural groups are Tarapacá, Atacama-Alto Loa and Antofagasta. The Tarapacá cultural group expanded its territories from the Camiña valley by the north to the Loa River by the south, in the endorheic territories of the Atacama Desert (Uribe, 2006). These groups

were characterised by having strong connections between the coast and valleys. They show a clear cultural style in the pottery (with the Pica Charcollo, Pica Chiza and Pica Gris alisado types) and textile objects, shared by the coastal and valley sites (Núñez, 1984; Moragas, 1995; Agüero et al., 1997; Uribe 2006). The Atacama cultural group, on the other hand were located 200 km from the coast, close to the Andes Mountains, next to the Atacama Basin at an elevation of 2.450 masl (Núñez, 1995)(Figure 1.1). The Alto Loa groups related to the Atacama ones were based in the highlands of the Andes, next to the upper course of the Loa River above 3000 masl. In contrast to Tarapacá these groups do not show evidence of strong connections with the coast (Schiappacasse et al., 1989; Uribe et al., 2004). Both, the Atacama and Alto Loa groups, also had their own local textile and pottery types (i.e. Dupont, Rojo violáceo, Turi Rojo Alisado, Turi Gris Alisado pottery types). The Antofagasta groups were located next to the coast, close to the homonym city (Antofagasta) (Figure 1.1), having an economy mainly based on marine exploitation (Ballester and Clarot, 2014). Pottery and textile are not as frequent as in the valleys showing rather material evidence related to marine activities. These three cultural groups will be described in more detail in Chapter 3.

1.2 How can isotope analysis help addressing questions about human migration during the LIP? A multi-isotope approach for studying diet and mobility patterns

Archaeological evidence such as pottery, textiles, lithics, faunal and botanical remains, are useful tools when studying past human populations. However, they present limitations since they only provide an indirect approach for studying life-ways. As mentioned before, findings of foreign objects in the archaeological record do not necessarily mean that the manufacturer was actually present there. These objects could have been brought through trade or exchange. A similar situation occurs when studying human diet in the past. The presence of determined zooarchaeological and archaeobotanical remains in the archaeological record does not necessarily mean they were consumed. Even though bioanthropological studies on oral health (Hillson, 1996) can give insights on the type of diet consumed during the life of an

individual, they are still indirect. Isotopic analysis on ancient human remains is a direct tool for studying palaeodiet and human mobility patterns, being quite useful for having a closer approximation to the individual's life-way (van der Merwe and Vogel, 1978; Schoeninger and DeNiro, 1984; Schwarcz and Schoeninger, 1991). By using stable isotope analysis on human remains from northern Chile, questions about mobility patterns during the LIP could be addressed through a direct approach. In order to test the presence or absence of colonial groups in the lowlands of the Atacama Desert, stable isotope analysis of carbon, nitrogen and oxygen will be carry out together with radiogenic strontium isotopes.

Now, how could these isotopes give insights about the diet and mobility patterns in the past? The application of stable carbon and nitrogen isotope analysis allows the study of human palaeodiet by showing differences in the isotopic ratios ($^{13}C/^{12}C$ and $^{15}N/^{14}N$) of a determined tissue such as bone collagen or hair keratin. Stable carbon and nitrogen isotopes are integrated to the human body through diet. Carbon isotopes are used for differentiating between C_3 and C_4 plants as well as between the ingestion of terrestrial and marine fauna. Wild plants and crops show differences in their $\delta^{13}C$ values depending on the photosynthetic pathway they follow. C_3 plants follow the Calvin Cycle showing global values between -26‰ to -27‰; on the other hand, plants that follow the C_4 photosynthetic pathway show higher $\delta^{13}C$ values with an average of -13‰ (Smith and Epstein, 1971; O'Leary, 1981). Maize was the main C_4 crop consumed during pre-Columbine times in South America. Hence, high $\delta^{13}C$ values in human samples could be suggesting the ingestion of this crop. However, a marine based diet can also increase the carbon isotope values on bone collagen and hair keratin. Marine carbonates are enriched in ^{13}C, and at the same time, the photosynthesis process of dissolved CO_2 by phytoplankton goes through less fractionation than C_3 plants, increasing the $\delta^{13}C$ values (Chisholm et al., 1982; Richards and Hedges, 1999). This situation makes difficult to differentiate between the ingestion of coastal resources and C_4 crops. This is because carbon coming from protein sources will preferentially be routed to bone collagen,

the organic fraction of bone (Ambrose and Norr, 1993; Tieszen and Fagre, 1993). However, the inorganic fraction of bone and enamel, bioapatite, will instead show the overall diet consumed by an individual, since it receives its carbon composition from proteins, carbohydrates and lipids (Ambrose and Norr, 1993; Tieszen and Fagre, 1993). By using both the organic and inorganic fractions for isotope analysis, problems associated with the overlap of values between C_4 and marine resources could be avoided.

Nitrogen isotopes are firstly assimilated from the atmosphere and soils by the primary producers, plants. Then they are incorporated through diet to the protein composition of animals and lately humans. It has been observed that there is enrichment in ^{15}N of about 3–5‰ that occurs between prey and consumer (Schoeninger and DeNiro, 1984) in each trophic level. Marine fauna will tend to show higher nitrogen isotopes values due to the longer food chains present in the sea, contrasting to the terrestrial ecosystems (Schoeninger and DeNiro, 1984). Hence, carbon and nitrogen isotopes together will facilitate the differentiation between marine and terrestrial diets. However, the $\delta^{15}N$ values of an animal or human can also be affected by a number of factors including aridity, use of fertilisers, amount of rainfall and elevation, and herbivore gut physiology (Heaton, 1987; Ambrose 1991; Sponheimer et al., 2003; Hedges and Reynard 2007; Szpak et al., 2012).

Oxygen isotopes can be used for studying residential mobility (e.g. White et al., 2004a,b; Knudson, 2009), together with radiogenic strontium isotopes (e.g. Sealy et al., 1995; Price et al., 2004; Bentley, 2006; Knudson and Price, 2007). The technique is based on the assumption that oxygen isotope values of bone or enamel apatite should reflect the isotopic composition of the water consumed by the individual in the period during which the tissue (bone or enamel) was formed. The $\delta^{18}O$ values of the meteoric water consumed will show variation due to factors such as temperature, amount of rainfall, latitude, altitude and evaporation rates (Dansgaard, 1964; Rozanski et al., 1993; Sharp, 2007).

Radiogenic strontium isotopes can provide insights on the place of origin of the individuals studied. The isotopic strontium ratios will vary depending on the radioactivity decay of

Rubidium-87 in different types of bedrock. Rubidium will decay producing ^{87}Sr (Faure and Powell, 1972). The older the bedrock, the higher the ^{87}Sr concentration will be. Thus, depending on the local geology of the study area, the $^{87}Sr/^{86}Sr$ ratios will be higher or lower (Faure and Powell, 1972). Strontium isotopes are incorporated to human tissues through diet being routed to the inorganic fraction of bone and enamel. In the bioapatite fraction calcium is replaced by strontium. In order to compare the $^{87}Sr/^{86}Sr$ ratios in the human tissues with the local geology it is essential to have a bio-available strontium map (Evans et al., 2009; Snoeck et al., 2016). Strontium isotope ratios can be altered by different factors such as erosion or the effects of sea fog on the bedrocks and/or plants (Bentley, 2006; Evans et al., 2009). For this reason, the geological values from the bedrock cannot be directly compared to the human strontium isotope composition.

It is worth mentioning that the isotopic composition of plants, animals and humans could be affected by the local geographical conditions of the study area. The Atacama Desert is characterised by a particular environment, ecosystem and geology, being the driest desert in the world with limited water resources (Ericksen, 1983). The particularities of the Atacama geography together with its effects on the isotopic composition of flora, fauna and hydrology will be further discussed in Chapter 2.

Following the previous antecedents, carbon and nitrogen isotopes will give insights on the diet consumed during the LIP. Considering northern Chile's geographical areas - coast, valleys and highlands (Figure 1.1), variations are expected in the human dietary patterns since different resources were available for consumption in each ecological zone (Troll, 1958). For instance, marine resources will be present by the coast; crops such as maize, squash, chilli and beans will be available in the valleys where the conditions are suitable for their sowing and harvesting, together with wild fruits; while camelids, flamingos and small rodent can be found at the highlands and *altiplano* together with potatoes and *quinoa*.

Oxygen isotopes should show variation between the ecological zones since there are differences in altitude, temperature, and amount of rainfall, between others. Hence, water sources or rivers closer to the highlands would show low $\delta^{18}O$ values in comparison to those closer to the coast where higher evaporation rates leads to increasing enrichment in ^{18}O. However, the study area only has a few rivers reaching the sea. The Atacama Desert has a complex hydrological system with plenty of groundwater sources and salt lakes. Springs and oases were likely the most common drinking-water source for humans in the past. In contrast to rivers, springs and oases are not subject to the same evaporation rates. In addition, they are mainly fed directly by aquifers that come from the highlands or *altiplano* (Magaritz et al., 1990; Aravena, 1995). These factors lead to lower $\delta^{18}O$ values in the meteoric waters (Magaritz et al., 1990; Aravena, 1995).

Radiogenic strontium isotopes should also present some variation since northern Chile's geology is quite diverse, composed by older bedrocks (Jurassic period) by the coast and younger ones by the Andes Mountains (Miocene-Quaternary periods)[1].

1.3 Stable isotope analysis for studying diet and mobility during the LIP in the Atacama Desert, what we know so far.

Studies on stable isotope in northern Chile have increased only during the last eight years (Knudson and Torres-Rouff 2009; Nado et al., 2012; Santana et al., 2012; Torres-Rouff et al., 2012; Roberts et al., 2013; Pestle et al., 2015: Santana-Sagredo et al., 2015a; Santana Sagredo et al., 2015b; Torres-Rouff et al., 2015; Uribe et al., 2016). Even though many studies have been published about human palaeodiet and mobility in the Atacama Desert, so far no local baselines for carbon, nitrogen, oxygen and strontium isotopes have been produced. Tieszen and Chapman (1992) have undertaken the only carbon and nitrogen isotope ecology study for the coast and highlands of Arica, close to the Chilean border with Peru (Figure 1.1). The results of this research show very high stable nitrogen isotope ($\delta^{15}N$)

[1] Information obtained from SERNAGEOMIN (Servicio Nacional de Geología y Minería, Gobierno de Chile).

values for fish, marine invertebrates and vertebrates (averaging 19.1±2.1‰, 16.2±2.3‰ and 18.5±1.7‰, respectively).

Just five studies addressing human mobility and subsistence in the LIP have been published so far for northern Chile (Tieszen et al., 1992; Aufderheide and Santoro, 1999; Knudson and Torres-Rouff, 2009; Santana-Sagredo et al., 2015a,b). Each studied different areas in northern Chile including the occidental valleys close to Arica (Tieszen et al., 1992; Aufderheide and Santoro, 1999), the Tarapacá cultural groups (Santana-Sagredo et al., 2015a,b) and the Atacama-Alto Loa groups (Knudson and Torres-Rouff, 2009; Santana-Sagredo et al., 2015a). Groups close to or in connection with the coast show high values for $\delta^{13}C$ and $\delta^{15}N$ (Tieszen et al., 1992; Aufderheide and Santoro; Santana-Sagredo et al., 2015a,b) in association with marine consumption, whereas groups distant to the coast and closer to the highlands show rather lower values suggesting terrestrial diets (Knudson and Torres-Rouff, 2009; Santana-Sagredo et al., 2015a). The individual results that suggest marine diet consumption show quite high values, usually above 20‰.

These five studies show isotopic values that are in agreement with the local faunal and vegetal evidence found at the sites. From the few cases studied, the human diets appear to be quite local and associated with the available resources from the areas inhabited.

However, two of these studies (Santana-Sagredo et al., 2015a,b) show the presence of non-local individuals buried in the cemeteries of Pica 8 and Cementerio Oriente de Quillagua, following their quite low $\delta^{13}C$, $\delta^{15}N$ and $\delta^{18}O$ values, suggesting a possible origin in the *altiplano*. In the case of Pica 8 five out of thirty individuals were considered as outliers (Santana-Sagredo et al., 2015a), while for Quillagua four out of twenty-three were suggested as non-locals (Santana-Sagredo et al., 2015b). In contrast to these two studies, Knudson and Torres-Rouff (2009) did not find any outlier individuals using oxygen and strontium isotopes in the cemetery of Caspana in the Alto Loa region. All of the previous isotopic work in northern Chile will be discussed in detail in Chapter 5.

The questions that arise out of these studies include the following: why are just a few (apparently) non-local individuals identified in the valley sites? Why are there, apparently, no outlier individuals in the highlands? What was the situation in coastal sites? And more importantly, how does this evidence relate to the mobility models previously described?

From the research carried out so far, it appears mobility patterns were probably more complex than what has been proposed from the archaeology and ethnohistorical hypotheses.

For this reason, by using a multi-isotope approach the old questions about human mobility during the LIP will be revisited using a greatly expanded study area from the highlands in the Andes Mountains to the Pacific coast.

1.4 Research Questions, Hypotheses, Aims and Objectives

1.4.1 Research Questions

Based on the outline presented above this thesis will intend to answer the following research questions:

- What were the mobility and dietary patterns of the Tarapacá, Atacama-Alto Loa and Antofagasta cultural groups during the LIP in northern Chile?
- How does the isotopic evidence on human mobility and dietary patterns relate to the vertical archipelago (Murra, 1972) and gyratory mobility (Núñez and Dillehay, 1995) models during the LIP?

1.4.2 Hypotheses

Following the isotopic evidence obtained so far for northern Chile, it is proposed that:

- Mobility and dietary patterns were directly associated with the cultural practices of each group studied (Tarapacá, Atacama-Loa and Antofagasta), being different between them and showing a strong local component.

- During the LIP there were no *altiplano* colonies in the lowlands but rather a reduced number of foreign individuals sharing the same physical space with the local cultural groups.
- Mobility was not reduced exclusively to specialised pastoralist groups from the highlands and/or *altiplano* through llama caravans. People from different cultural backgrounds moved between the coast and valleys, between valleys, coast to highlands, valleys to highlands and vice versa.

1.4.3 Aims

To test these hypotheses this thesis aims to characterise and evaluate the human mobility and dietary patterns in the life-ways of ancient populations from the Tarapacá, Atacama-Alto Loa and Antofagasta groups through the application of a multi-isotope analysis approach. This study will include Atacama Desert groups that inhabited sites from the high Andes to the Pacific coast.

At the same time, considering the lack of local baselines for carbon and nitrogen isotopes in the Tarapacá and Atacama-Alto Loa cultural areas, a complete isotopic framework for the food items consumed by local populations will be carried out. The building of this baseline will also consider exploring the reasons behind the considerable enrichment in ^{15}N reported by previous studies in northern Chile.

1.4.4 Objectives

To accomplish these aims, this research will consider the follow objectives:

- Generate an environmental reconstruction of the isotope ecology of the Tarapacá, Atacama-Alto Loa and Antofagasta areas measuring isotopic values for carbon and nitrogen in modern and archaeological samples of vegetation and fauna from the coast, valleys, and highlands. The samples analysed will include modern and archaeological wild plants and crops, as well as wild and domesticated animals.

- Characterise the diet of human groups from the Tarapacá, Atacama-Alto Loa and Antofagasta cultural groups through the application of stable isotopes of carbon (from bone collagen, hair keratin, bone and enamel apatite) and nitrogen (from bone collagen and hair keratin).
- Contextualize the chronological framework of the samples through the radiocarbon dating of human samples from bone together with other archaeological materials associated with them, with appropriate consideration of any reservoir effects.
- Generate a local bio-available map for strontium isotopes in northern Chile, through the analysis of modern and archaeological plants from the Tarapacá, Atacama-Alto Loa and Antofagasta areas. This map will be used for comparison with the results obtained for human samples.
- Characterise the mobility patterns of the Tarapacá, Atacama-Alto Loa and Antofagasta individuals through the application of stable isotope analysis of oxygen (bone and enamel apatite) and radiogenic strontium isotope (enamel apatite) analysis in archaeological human remains.

1.4.5 Expected results

The following results are expected in this work:

- In terms of dietary patterns it is expected that the carbon and nitrogen isotope compositions would be related to the local diets. For the case of the Tarapacá cultural groups a mixed marine-terrestrial with C_3-C_4 plant consumption is expected; for the Atacama-Alto Loa groups a rather terrestrial diet is expected with a mixed consumption of C_3 and C_4 resources; while the Antofagasta groups should present a marine diet based on the archaeological evidence. These expected results contrast with what would be expected for a highland-*altiplano* diet mainly based on terrestrial and C_3 resources, with low $\delta^{13}C$ and $\delta^{15}N$ values.
- High values of $\delta^{18}O$ are expected for all the local groups, contrasting with the low $\delta^{18}O$ values that should be observed for the highland-*altiplano* people. Strontium isotopes

should show values associated with the local geology of the Tarapacá, Atacama Alto-Loa and Antofagasta sites of occupation.

1.5 Thesis structure

Chapter 2 presents a description on the Atacama Desert's geography and discusses the possible complications that arise when applying stable isotope analysis in arid regions.

Chapter 3 presents an archaeological background of the region, including a discussion of the classical models of mobility together with descriptions of the cultural areas and the sites studied.

Chapter 4 presents the results of carbon and nitrogen analysis for modern and archaeological flora and fauna. A new isotopic baseline for northern Chile is presented here.

Chapter 5 presents the results obtained for ancient diet reconstruction on human remains from the different cultural areas studied. Here isotopic results for teeth, bone and hair samples will be presented and discussed.

Chapter 6 discusses the temporal framework of the Pica 8 cemetery, presenting the results for paired human-terrestrial radiocarbon dates from the same graves on 23 samples. Paired dates were carried out in order to avoid problems related to the marine reservoir effect (MRE). Considering the high $\delta^{15}N$ values obtained for the individuals from the cemetery Pica 8 (Santana-Sagredo et al., 2015a), it is likely that the dates could be significantly affected by the MRE.

Chapter 7 presents the results of radiogenic strontium and oxygen isotope analysis on ancient human remains from the Atacama Desert in order to better understand past mobility patterns. In addition, a local baseline for radiogenic strontium isotopes is presented.

Chapter 8 presents an overall discussion of the results obtained in this work. Dietary and mobility patterns will be discussed on the light of the new results, contrasting them with the available archaeological evidence and the classic mobility models. In addition, the

conclusions of this research will be presented in relation to the hypotheses and aims proposed in this thesis.

Chapter 2

Geography, Ecology and Isotopic characteristics of the Atacama Desert

This chapter will present a general description of the geographical, environmental and ecological conditions of the Atacama Desert. In addition, the isotope composition of resources associated with the different ecological zones will be briefly described, including flora, fauna and meteoric water sources (groundwater, springs, oases and river systems). These aspects will be discussed considering the advantages and limitations that they have when using and interpreting stable oxygen isotopes for studying human residential mobility in arid environments.

2.1. Introduction: Delimitation of the study area

The archaeological sites studied in this research are located in different geographical areas of the Atacama Desert, northern Chile. Understanding the main features of the region's geography is fundamental to better comprehend the social dynamics that characterised the populations of the Late Intermediate Period (AD 900-1450).

The research area is located in the endorheic zones (i.e. no rivers reach the coast) of the Atacama Desert (Figure 2.1), delimitated between the Camiña ravine (19º 33' Lat S) in the north and the Loa River (21º26' Lat S) in the south (the only river that reaches the coast in the study area), together with the Atacama basin (22º50' Lat S) by the south-west and the Antofagasta coast by the west.

As mentioned in chapter one, three main cultural groups are study here: the Tarapacá, the Atacama-Alto Loa and the Antofagasta. The territorial expansion of each of these cultural groups is presented in Figure 2.2 The Tarapacá cultural groups lived between the Camiña ravine by the north and the lower course of the Loa River by the south (Uribe, 2006). They expanded their occupations from the Pacific Coast to the highlands

in the Andes Mountains. The Atacama-Alto Loa cultural groups on the other hand, were located next to and in the pre-cordillera area (Núñez, 1995). Occupations were mainly based next to the Atacama Basin, in the fertile Atacama oases located by the north of the salt lake. In addition, these groups also lived in the upper course of the Loa River, in the highlands of the Andes with sites located above 3000 masl (Schiappacasse et al., 1989).

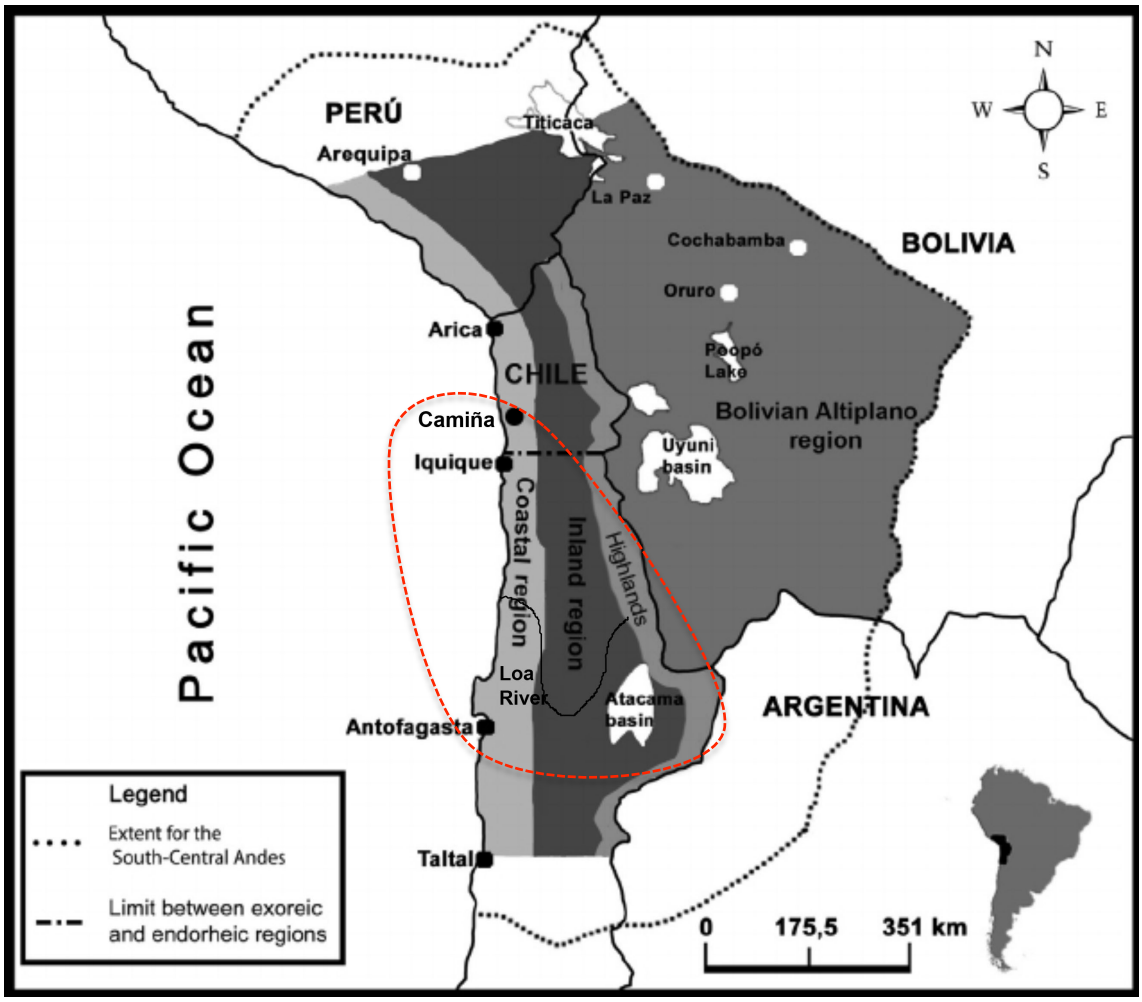


Figure 2.1. Map showing the delimitation of the study area (red-circle dotted line) in northern Chile.

The Antofagasta groups were mainly based next to the coast of the homonym city showing a clear marine adaption (Ballester and Clarot, 2014).

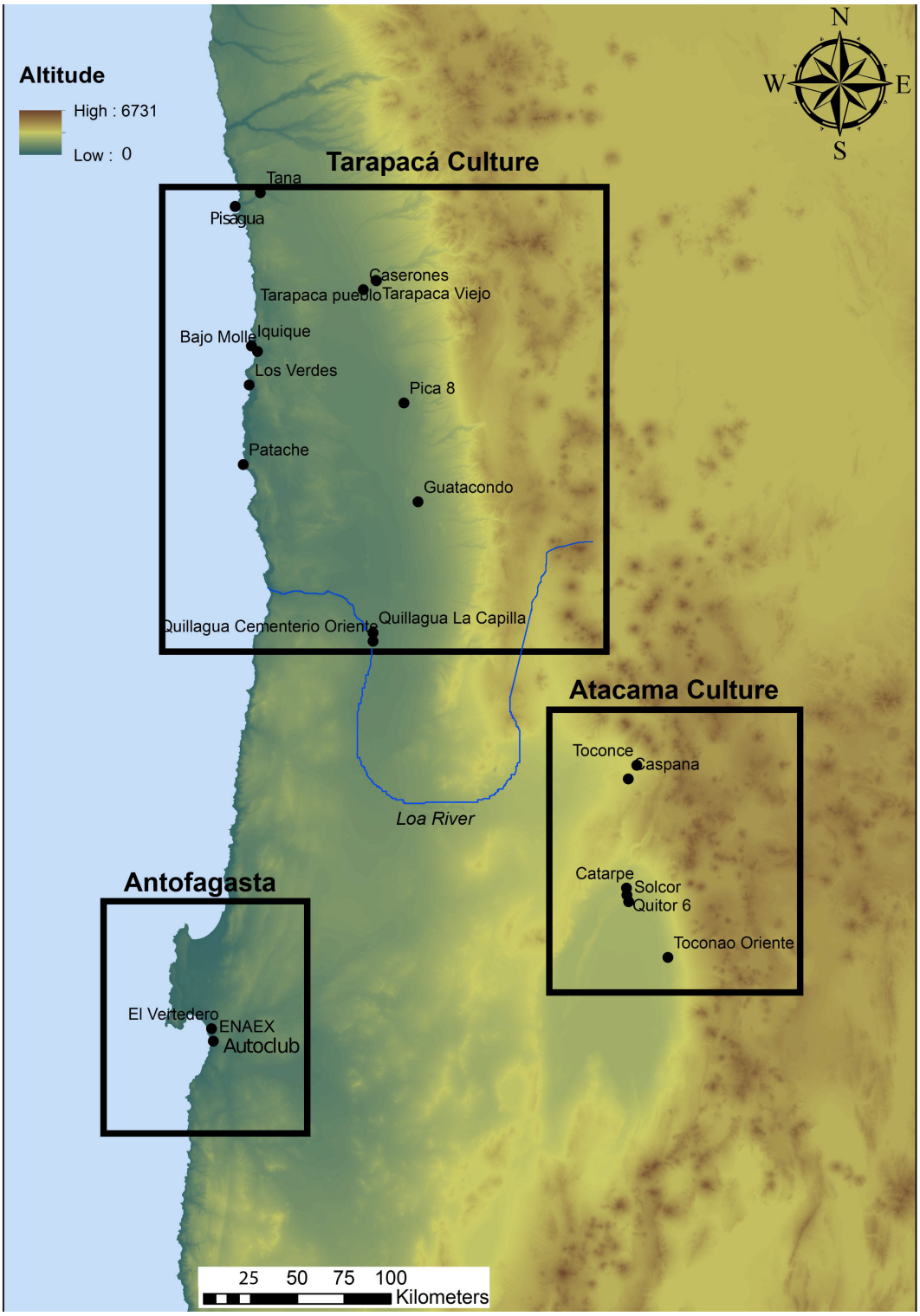


Figure 2.2 Map of northern Chile showing the delimitation of the three cultural areas studied in this research: The Tarapacá, Atacama-Alto Loa and Antofagasta.

2.2 The Atacama Desert and its main geographical units

The dynamics that characterise how ancient populations lived and moved through the landscape is intrinsically related to local geography. The Atacama Desert is the driest desert in the world (Ericksen, 1983; Clarke, 2006). It occupies a long extension of land from southern Peru (18ºS) to northern Chile (27ºS) (Latorre et al., 2003; Latorre et al., 2005). The extreme hyperarid conditions of the Atacama are mainly caused by: the influence of the south Pacific anti-cyclone; the rainshadow effect of the Andes mountains that acts by blocking the advection of tropical moisture from the Amazon Basin; and the influence of the Humboldt Current (which limits the penetration of Pacific moisture inland, related to its very cold waters) (Gutierrez et al., 1998; Latorre et al., 2003; Clarke, 2006; Houston 2006). Rain is almost nil between 0-2000 masl, occurring sporadically and reaching values between 0.6-10 mm (Rundel et al., 1991; Aravena et al., 1999; Quade et al., 2007). The amount of precipitations increases with altitude, in the Andes Cordillera (Figure 2.3) (Aravena, 1995; Aravena et al., 1999). These precipitations come directly from the Atlantic Ocean and the Amazon Basin (Aravena, 1995; Aravena et al., 1999). In addition, temperature also decreases following the altitudinal gradient from the coast to the Andes (Quade et al., 2007).

At least four different geographical zones (Troll, 1958) can be recognised in the Atacama (Figure 2.4). These are: the narrow coastal fringe and the Coastal Cordillera next to it; valleys and intermediate depressions known as *pampa* (desert landscape); sloping plains or ravines close to the pre-cordillera area (*quebradas*); and the Andes Mountains, also known as *Cordillera de los Andes*, referring to the highlands and the *altiplano*. From the coast to the Andes the environmental as well as climatic conditions change when altitude increases.

This thesis will work directly with the ecological zones: coast, valleys or *pampa*, pre-cordillera and highlands, where the archaeological sites of the different cultural groups

are located. A general description of each of these zones is presented below, including the isotopic characteristics of their associated resources.

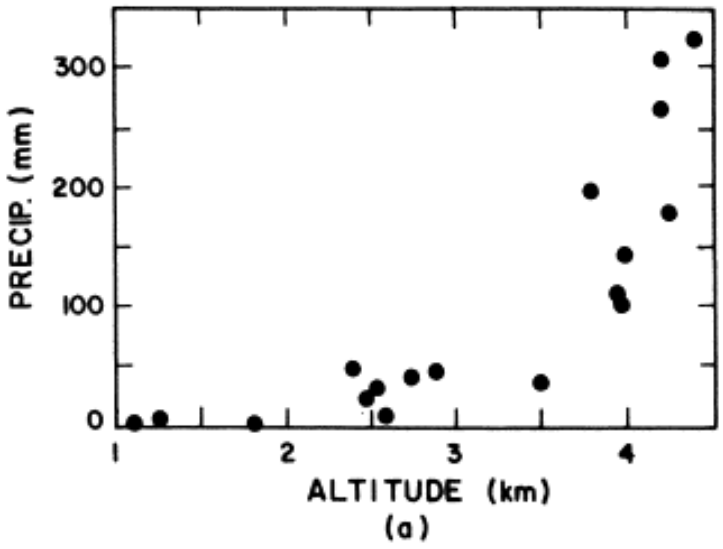


Figure 2.3. Relation between the amount of precipation and altitude in northern Chile. Figure taken from Aravena et al., (1999).

2.2.1 *Arid coast and Coastal Cordillera*

The coastal zones of northern Chile are characterised by being a narrow and stretched plain, having vegetation highly adapted to dry environments and a low diversity of terrestrial fauna (Marquet et al., 1998). Rain is almost absent in this area (Rundel et al., 1991; Aravena, 1995; Aravena et al., 1999), although it can occur during winter and under the influence of the climatic conditions of the El Niño Southern Oscillation (ENSO) (Holmgren et al., 2001; Thiel et al., 2007).

The main resources associated with the coast are the marine fauna of the Pacific Ocean (Siefeld and Vargas, 1996; Vásquez et al., 1998; Camus, 2001). The marine fauna is very diverse, with an important biodiversity that goes from plankton to seaweeds, mussels (*Concholepas concholepas*; *Fisurella latirmaginate*), fish (*Trachurus symetricus*; *Sarda chilensis*; *Paralabrax humeralis*) marine mammals (*Otaria flavescens*), and birds (*Larus belcheri*; *Larus modestus*; *Pelecanus thagus;*

Sula variegata) (Araya and Millie, 1992; Siefeld and Vargas, 1996; Vásquez et al., 1998; Camus, 2001).

The biodiversity of the Pacific Ocean in northern Chile is remarkably high because of the influence of the cold Humboldt Current and the complex upwelling system that characterises it (Craig, 1982; Vasquez et al., 1998; Camus, 2001; Thiel et al., 2007). Immediately beside the coast, the Coastal Cordillera abruptly appears with maximum altitudes that can reach 800-1000 meters above sea level (masl). This cordillera has an important function in the formation of fog by intercepting clouds coming from the Pacific, which occurs between 600 and 1000 masl (Evans and Ehleringer, 1994; Gutiérrez et al., 1998). This fog it is also known as *camanchaca*, being the main water source that allows the spread of vegetation in the desertic coast.

The types of coastal vegetation present in this area are plant communities such as trees (*Prosopis tamarugo* and *Atriplex madariagae*) (Gutiérrez et al., 1998), shrubs, cacti (Lycium, Ephedra, Frankenia, Opuntia, Eulychnia), herbs (*Nolana jaffuelli* and Alstroemeria) and courmous plants (*Zephyra elegans*) (Pinto, 2001). The types of terrestrial fauna that can be found are mainly small rodents (mainly *Phyllotis xanthopygus*) (Jaksic et al., 1999), scavenger birds (*Cathartes aura jota*) and the small reptile *Microlophus atacamensis.*

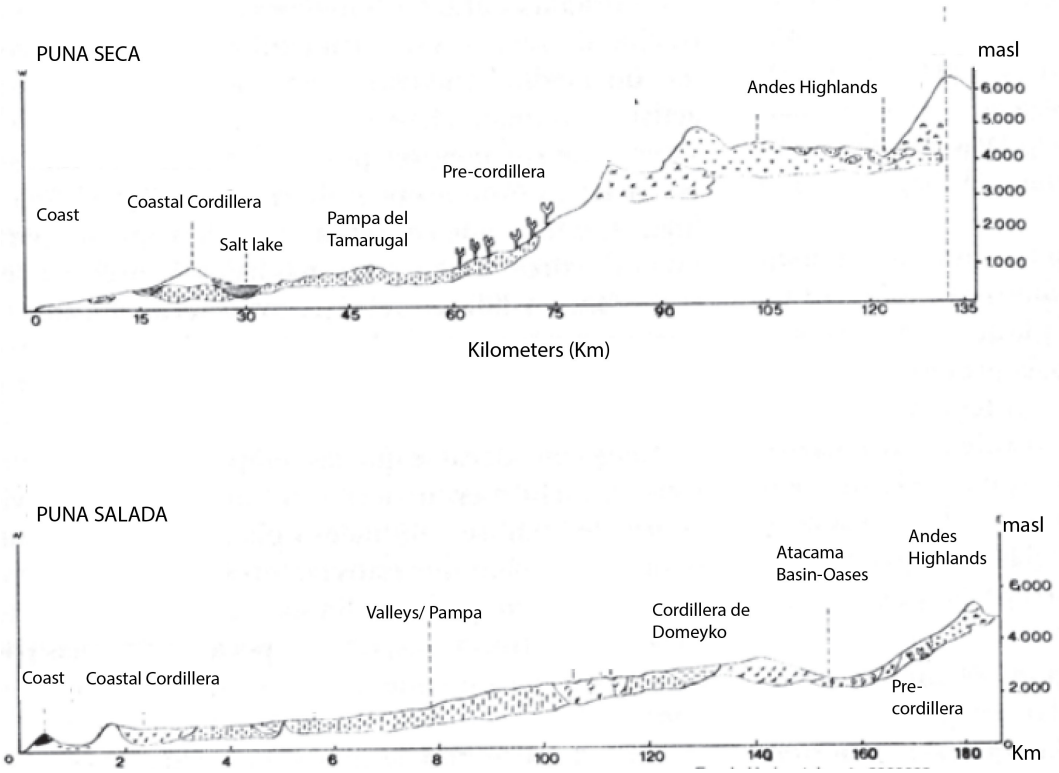


Figure 2.4. Transect showing the different ecological zones of northern Chile, including both Andes Cordillera division between *Puna Seca* and *Puna Salada* (modified from Núñez and Santoro, 1988).

2.2.2 *Intermediate depression- valleys (pampa)*

The Intermediate depression (or valleys-*pampa*) is in between the Coastal Cordillera and the pre-cordillera area at an altitude between 900-2000 masl and is characterized by its expanded flat area (Gutierrez et al., 1998; Houston, 2006). Rainfall here is almost non-existent and is the most arid area in the Atacama Desert (Aravena, 1995; Latorre et al., 2005). There is an almost complete absence of vegetation. However, the presence of groundwater and springs, together with the Loa River, the only river that crosses the desert from the Andes to the ocean in the study area, make possible the presence of vegetation and fauna. These water sources have also been important for human occupations in the past as well as in the present.

Between the Camiña ravine and the Loa River, the main geographical feature in the valleys is the *Pampa del Tamarugal* (19º 17'-21º 30' S), a north-south plain basin at

1000-2000 masl, surrounded to the east by the Andes Cordillera and by the Coastal Cordillera to the west (Aravena, 1995). The few rivers present in *Pampa del Tamarugal* end up as recharge sources for the groundwater system of the region and salt lakes (Magaritz et al., 1990; Aravena, 1995; Aravena et al., 1999) (Figure 3). The presence of groundwater and springs in this *pampa* has allowed the development of fertile oases and even forests of *Prosopis sp*. However, nowadays this forest is reduced considerably, due to human intervention in the area, mainly in the form of mining activities (Ericksen, 1983). One of the most important oases in the *Pampa del Tamarugal* is Pica (Figure 2.2), being a suitable place for agricultural activities.

The Loa River south of the Tarapacá region reaches the sea from the Andes leading to the formation of many oases through its course, such as Calama and Quillagua. The types of vegetation found in *Pampa del Tamarugal* and next to the Loa River are *Prosopis alba*, *Prosopis algarrobo*, *Schinus molle*, *Atriplex atacamensis* and *Geoffroea decorticans*, together with some shrubs and herbs (Gutierrez et al., 1998). Because of the very dry conditions of this area, the range of fauna is very limited. The fauna present in the valleys are mainly rodents such as *Phyllotis xanthopygus* (Jaksic et al., 1999). The Loa River used to have a rich fauna component, with freshwater fish (the most common species being *Basilichtys semitilus*) and frogs (Marquet et al., 1998; Torres-Rouff et al., 2012). However, nowadays life in the river is much reduced because of all the contamination received from the mining activities.

2.2.3 The Andes Cordillera: Pre-cordillera and Highlands

The pre-codillera and highlands altitude in the Andes Cordillera ranges from about 2500 masl up to 6000 masl (Troll, 1958; Núñez and Santoro, 1988; Latorre et al., 2003; Latorre et al., 2005; Grosjean and Veit, 2006). This is the only geographical unit where precipitation occurs. Here, rainfall increases with altitude due to the colder conditions present at higher altitudes (Sharp, 2007). For this reason, the Andes Cordillera presents a wider range of flora and fauna species, by having more accessible water

sources compared to the arid desert. The highlands differentiate to the *altiplano*, with the last one being a large expansion of flat land at high altitudes, as by geographical features that can be found in Bolivia. In the Andes Cordillera of northern Chile, the mountain range is quite irregular, not showing flat surfaces.

Due to its variable geographical features, the Andean Cordillera can be sub-classified into two main segments known as *Puna* Seca (Dry *Puna*) and *Puna* Salada (Salt *Puna*) (Troll, 1958; Santoro and Núñez, 1988). The term *puna* refers to the high areas of the Andes Mountains, above 3000 masl. The *Puna Seca* in Chile expands from the boundary with Peru to latitude 20º, whereas the *Puna Salada* expands from latitude 20º until 26º (Troll, 1958; Núñez and Santoro, 1988). Most of the *Puna Seca* is in the area related to the Tarapacá region, while the *Puna Salada* is in the Atacama and Alto Loa cultural area. In contrast to the *Puna Seca*, the *Puna Salada* is associated with an important extension of the absolute desert in the pampa before reaching the Andes. The Andes Cordillera at the *Puna Salada* only begins between 2500-2800 masl, and it is much more distant from the coast in comparison with the *Puna Seca*, at about 200 km. The *Puna Seca,* in contrast, is only 100-120 km distant from the coast (Troll, 1958; Núñez and Santoro, 1988).

In the *Puna Salada* (thus the Atacama-Alto Loa cultural area), another geographical feature is important. This is the division of the Andes Mountains into two mountain ranges, showing a new chain in direction to the southwest. This is the *Cordillera de Domeyko*, which is lower in altitude than the Cordillera de los Andes, reaching a maximum of 3800 masl (Boschetti et al., 2007). Between the two cordilleras an important plain expands, containing one of the most important salt lakes in Chile: the Atacama Salt Lake (2450 masl) (Boschetti et al., 2007). The salt lake forms an important point of life, mainly for birds such as flamingos (*Phoenicopterus chilensis*) known as *parinas* that are adapted to the consumption of salty water. It is in between these two mountain ranges and next to the Atacama salt lake where the Atacama oases area located. These oases are mainly fed by the presence of two rivers that

reach and fill the Atacama Salt Lake: the San Pedro and Vilama rivers (Boschetti et al., 2007).

Together with this main division of the Andes Cordillera in *Puna Seca* and *Puna Salada*, the *Puna* itself can be subdivided. This subdivision is important to better understand the distribution of vegetation and fauna in the different elevation levels of the mountains (Troll, 1958; Núñez and Santoro, 1988; Gutiérrez, 1998):

- Pre-cordilleran valley or pre-*puna*. This ecozone is located at the foot of the mountains; however, it is a different area from the valleys/*pampa*. Usually it is between 2000 and 3000 masl. This is the place where the Atacama oases as well as the Atacama salt lake are located. Vegetation includes shrubs such as *Acantholipia deserticola, Ambrosia artemisloides, Hologyne macrogyne,* and *Helioanthrocereus atacamensis*. Trees such as *Prosopis algarrobo* and *Geoffroea decorticans* are also found here.
- Cordilleran valleys or *Puna*. Located between 3000 and 4200 masl, this ecological zone shows the highest vegetation and fauna abundance and diversity. Here the amount of rainfall increases, reaching 200-300 mm in summer time. It is common to find springs and small lakes at these altitudes where most of the fauna concentrates. These locations are known as *bofedales* (alpine peatlands), which are suitable for pastoralism (Squeo et al., 2006). Some of the most frequent vegetal species found at this elevetations are *Acantholippia desertícola*, *Baccharis boliviensis, Baccharis incarum, Fabiana densa*, *Senecio eriophyton*. The fauna present at these altitudes is characterised by rodents, camelids, and birds including: *Lagidium viscacia*, C*hinchilla chinchilla*, *Oreaylurus jacobita*, *Vicugna vicugna, Pterocnemia pennata tarapacensis*, *Tinamotis pentlandi*, *Phoenicopanus sp*., *Folica gigantean*, *Larus serranus*. Domesticated camelids such as *Lama glama* and *Lama pacos* can be found in this area, usually consuming resources close to the peatlands.

- High Puna (also known as High Andean belt). The high puna reaches very high altitudes, ca. 4000-6000 masl. This is a steppe zone with high fluctuations in temperature. Vegetation here is still present but in lower frequency, with plants such as tussock grasses known as *pajonales* (*Colaeataenia ginerioides*) and cushion plants known as *llareta* (*Azorella yareta*) that are adapted to resist the hard and cold conditions of high altitudes.

2.3. Carbon and nitrogen isotope composition of local plant and animals in the driest desert of the world

Stable carbon and nitrogen isotope show a different composition in the arid Atacama Desert (compared to other parts of the world) due to the extreme conditions that characterise this environment. Even though there are not local isotope baselines, with the exception of the one published by Tieszen and Chapman (1992), isotopic research carried out in different locations has given new insights on the particular values of $\delta^{13}C$ and $\delta^{15}N$ for northern Chile (Ehleringer et al., 1992; Tieszen and Chapman, 1992; Evans and Ehleringer, 1994; Ehleringer et al, 1998; Quade et al., 2007; López et al., 2013; Díaz et al., 2016).

Vegetation in the coast and valleys of the Atacama is scarce and limited to places with water availability, contrasting with the highlands where plant and animal resources are more abundant (Troll, 1958; Quade et al., 2007). In all of the ecological zones, C_3 plants are predominant (Tieszen and Chapman, 1992; Ehleringer et al., 1998). Nevertheless, C_4 plants are present from 0 to 3500 masl. C_4 species occurring at the coast are *Atriplex mucronata* and *Cistanthes sp*.; for the valleys/pampa the species are *Atriplex imbricata,* and *Atriplex sp.*; and finally for the highlands the species are *Aristida adscensionsis*, *Bouteloua simplex*, *Enneapogon devauxii* and *Munroa decumbens* (Tieszen and Chapman, 1993; Ehleringer et al., 1998; Quade et al., 2007). The range of $\delta^{13}C$ values observed for these different C_4 species is between -18.4‰ to -14‰

(Tieszen and Chapman, 1993; Ehleringer et al., 1998; Quade et al., 2007). Different CAM plants are also present along the altitudinal gradient, including species such as *Copiapa cinera*, *Eulychnia iquiquensis* and *Opuntia sp*. showing $\delta^{13}C$ values around -14‰ (Quade et al., 2007).

Even though C_3 plants show a greater predominance in the Atacama Desert their carbon isotope isotopic composition is enriched in ^{13}C compared to plants that are not under water stress. Due to the arid conditions and in order to have an efficient water use, C_3 plants growing by the coast and valleys present higher stomatal closure leading to less discrimination against $^{13}CO_2$ (Ehleringer et al., 1998; Quade et al., 2007). As mentioned in Chapter 1, the average values observed for C_3 plants are between -26‰ to -27‰, however in northern Chile the mean value for C_3 plants is around -23‰ (Quade et al., 2007). Lower values of $\delta^{13}C$ are observed for the highlands (Quade et al., 2007).

Not only plant's carbon isotope composition is affected by the dry conditions of the Atacama but also their $\delta^{15}N$ values. Evans and Ehleringer (1994) reported high $\delta^{15}N$ values for modern plants growing next to the coast of Paposo in northern Chile. The authors evaluated the nitrogen isotope values of different species growing below ($\delta^{15}N$ 9.2±0.4‰), in ($\delta^{15}N$ 10.6±0.6‰) and above ($\delta^{15}N$ 8.9±0.9‰) the fog zones of the arid coast. They did not see any differences related to the fog effect in the results, concluding the high $\delta^{15}N$ values of the plants could be due to the volatilisation of ammonia ($^{14}NH_4^+$) leading to soils enriched in ^{15}N (Evans and Ehleringer, 1994). This would affect directly the non-fixer species. Díaz et al. (2016) obtained similar results with modern plants enriched in ^{15}N, following a transect from the Atacama oases (2450 masl) to the highlands close to the Lejía Lake (above 4000 masl). Foliar $\delta^{15}N$ values present a maximum of 8.8‰. The high values were only reported for plants below 3000 masl. In addition, the mean nitrogen isotope value for soils is 8.2‰. Díaz et al., (2016) also suggest an influence of ammonia volatilisation in order to explain the enrichment

of plants in ^{15}N. Heaton et al. (1986) and Heaton (1987) also reported evidence of plants having high $\delta^{15}N$ values in arid environments from South Africa and Namibia. The authors also associate these results with preferential evaporation of ammonia molecules depleted in ^{15}N occurring in the soil.

During pre-columbine times different types of crops were available thanks to the specialised agricultural activities carried out in the valleys/*pampa* and the highlands. Agriculture was not possible by the coast due to the extreme arid conditions and the lack of water sources for maintaining the crops (Uribe, 2006). The main C_4 crop consumed in the past was maize (*Zea mays*), while the mean C_3 crops consumed were squash (*Lagenaria sp*.), beans (*Phaseolus vulgaris*) and chilli (*Capsicum chinense*) (Uribe, 2006). *Quinoa* (*Chenopodium quinoa*) and potatoes (*Solanum tuberosum*) (both C_3 crops) only grew at high altitudes above 3000 masl. Unfortunately, very few isotope analyses on archaeological crops have been carried out in northern Chile. There is only one publication so far for the coast of Pisagua (Aufderheide et al., 1994). The results show crops very enriched in ^{15}N ($\delta^{15}N$ value higher than 20‰). The authors relate these high values to diagenesis, following the same explanation given by Hastorf and DeNiro (1985) for different archaeological crop species very enriched in ^{15}N in sites of northern and central Perú. However, the possible use of manure in agriculture activities in the past might also have had an effect on these high nitrogen values (Finucane, 2007; Bogaard et al., 2007; Fraser et al., 2011; Szpak et al., 2012). A recent experimental study (Szpak et al. 2012) showed that application of llama dung and seabird guano increased the $\delta^{15}N$ from ca. +6‰ compared to unmanured maize to +13.9 ± 0.6‰ for the former and up to +38.1 ± 0.6‰ in the latter, respectively.

Regarding the environmental effects of aridity on animals, some physiological adaptations have been proposed. One of these is related to the recycling of urea depleted in ^{15}N (Sealy et al., 1987) in the body of herbivore animals, whereas the other is associated with the excretion of urea depleted in ^{15}N (Ambrose, 1991) that would

result in an increase in the bone collagen $\delta^{15}N$ values. However, variation in $\delta^{15}N$ values between herbivores is not only related to experiencing environmental stress. Sponheimer et al. (2003) have shown that there is significant interspecies variation due to gut physiology, even if feeding on exactly the same diet, with alpacas showing the highest $\delta^{15}N$ values when compared to llamas, horses, cattle, goat and rabbits.

However, the isotope composition of herbivores from the north of Chile is poorly known, with the exception of the analyses of modern fauna by Tieszen and Chapman (1992). The $\delta^{15}N$ values obtained for llamas (*Lama glama*), averaging ca. 6‰, are within the range expected for terrestrial herbivores not under the effects of environmental stress. However, values obtained from archaeological llamas from the Formative Period (Tulán 54 site) in the Atacama oases demonstrate higher values – ranging 9.8‰ to 13‰ – than those in modern llamas (López et al., 2013). Further research is needed to better understand the physiological adaptations, variations and isotope composition of camelids and other animals from northern Chile.

Not only terrestrial animals present unusual high $\delta^{15}N$ values but also modern marine fauna of the Pacific Ocean (Tieszen and Chapman, 1992). Supporting this is the observation that fish (19.1±2.1‰) exhibit higher average $\delta^{15}N$ values than sea mammals (18.5±1.7‰). Tieszen and Chapman (1992) suggest these results might be related to the complex upwelling system that characterises the Pacific Ocean, rather than a trophic level effect.

2.4 Hydrology and stable oxygen isotopes in the Atacama Desert

The hydrology system of northern Chile is quite complex. First of all, the absence of precipitations in the coast and valleys together with the reduced numbers of rivers that reach the coast, limit the water sources for human inhabitation of the area.

The oxygen isotope composition of meteoric water in the Atacama Desert is also particular and complex. As in other arid and semi-arid environments, evaporation (Magaritz et al., 1990; Aravena, 1995; Sharp, 2007) plays a major role in the $\delta^{18}O$ values of precipitations, groundwater, springs, rivers and salt lakes. Values for $\delta^{18}O$ in the coast and valleys are expected to be less negative to the ones from the highlands, due to the higher evaporation rates at lower altitudes, higher temperatures, reduced humidity conditions, and the almost lack of rainfall (Dansgaard, 1964; Sharp, 2007).

Figure 2.5 shows the differences in the oxygen isotope composition of precipitations between 2500 masl and 4000 masl (Aravena et al., 1999). The values are more negative at higher elevations above 3000 masl between -18‰ and -15‰ (SMOW), while for altitudes below 3000 mals the values range between -10‰ to -6‰ (SMOW) (Aravena et al., 1999). In addition, It has been reported that for arid and semi-arid regions the local meteoric water lines show a lower slope compared to the global water line (with a slope of ~8) between ~4-6 (Sharp, 2007). Even though the meteoric line for precipitations in the highlands of northern Chile has a slope of ~7 and similar to the GMWL (Aravena, 1995; Aravena et al., 1999), a lower slope is actually reflected in the local meteoric water lines for the Atacama Desert groundwater, springs and rivers as presented in Figures 6 and 7 (Aravena, 1995; Boschetti et al., 2007). The increased values are also related to the limited recharging of these water sources, coming directly from the precipitation occurring in the Andean highlands and *altiplano* that also suffer evaporation processes when condensing (Magaritz et al., 1989, Magaritz et al., 1990; Aravena, 1995; Aravena et al., 1999; Boschetti et al., 2007).

Based on these particular features of northern Chile's hydrology and its oxygen isotope values, a brief description is given for the water system of Pampa del Tamarugal (including the Pica oases) and the Atacama Basin (including the Atacama Salt Lake, the San Pedro River together with Loa River).

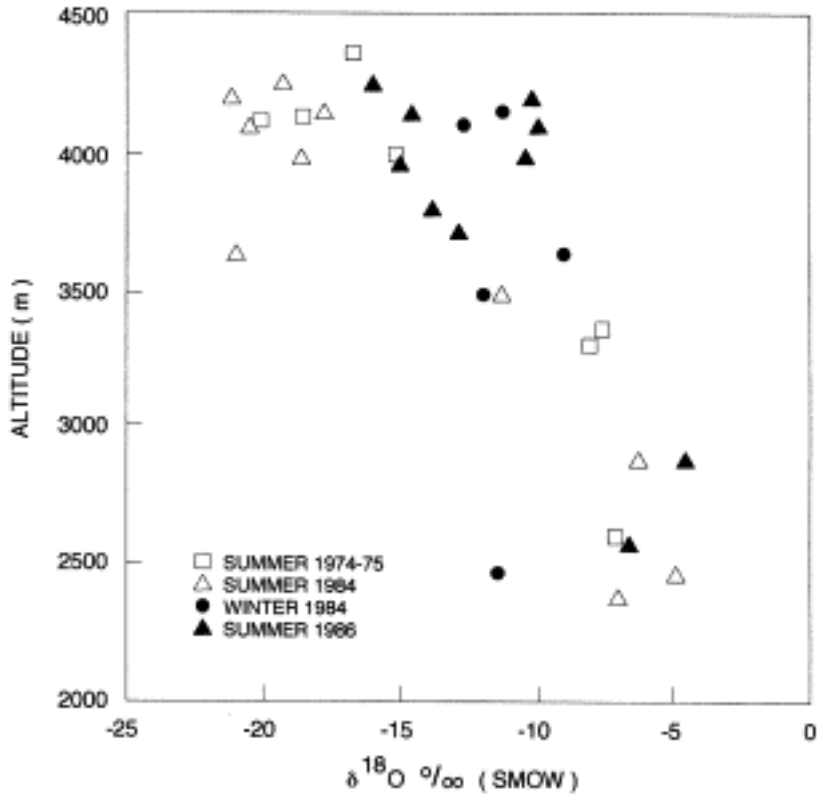


Figure 2.5. Bivariate plot showing $\delta^{18}O$ values in precipitations vs altitude in northern Chile. At higher altitudes (above 3500 masl) $\delta^{18}O$ values are lower. Figure taken from Aravena et al., 1999.

2.4.1 *Groundwater system of Pampa del Tamarugal*

The hydrology at *Pampa del Tamarugal* (22º 18' S) is dominated by the abundant presence of groundwater and springs (Magaritz et al., 1990). The groundwater that comes from the Andes flows in a northeast to southwest direction (Aravena, 1995). Even though most of this area is characterized by being endorheic, there are few rivers coming from the Andes but that do not reach the sea. Instead, these rivers end up recharging the groundwater system or salt lakes present in this area (Magaritz et al., 1989; Magaritz et al., 1990; Aravena, 1995; Aravena et al., 1999).

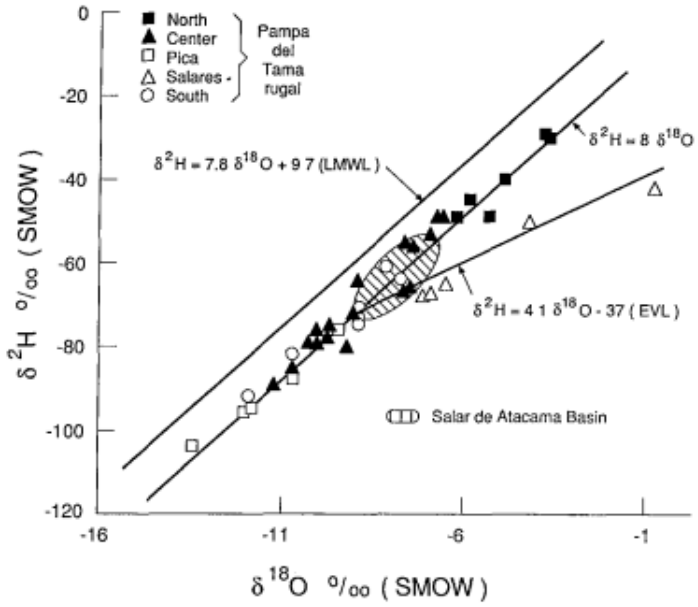


Figure 2.6. Bivariate plot showing $\delta^{18}O$ vs $\delta^{2}H$ in groundwater of Pampa del Tamarugal and Atacama Basin, including the MWL for northern Chile with a slope of 7.8 (based on precipitations) and the new MWL based on the groundwater values. Figure taken from Aravena, 1995.

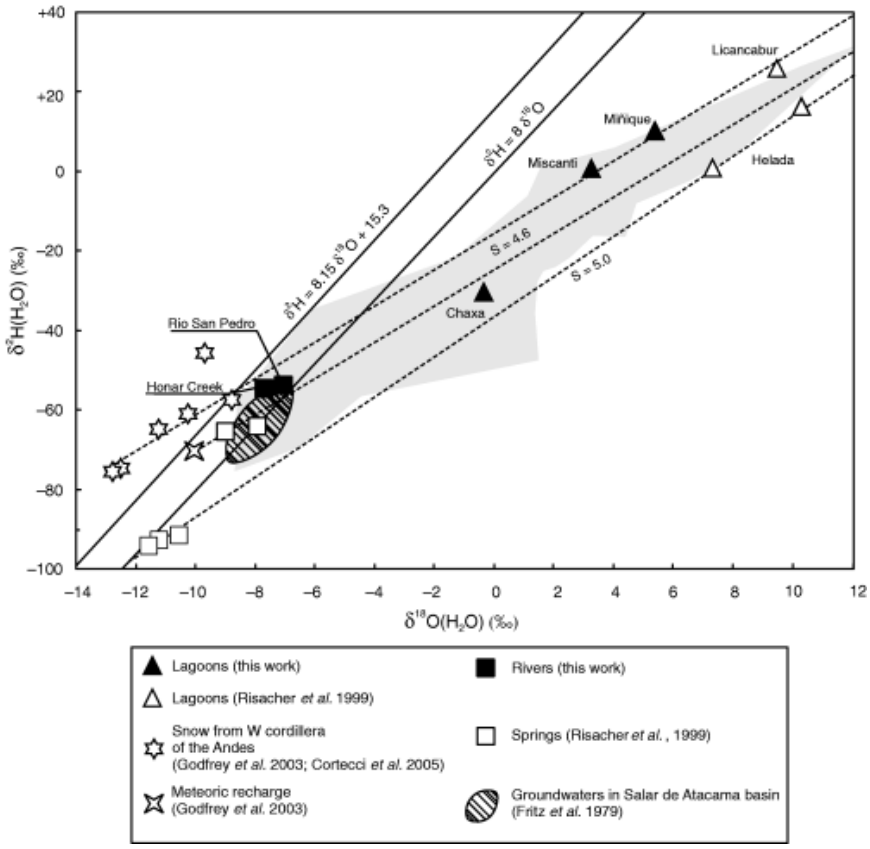


Figure 2.7. Bivariate plot showing $\delta^{18}O$ vs $\delta^{2}H$ in rivers, lagoons and groundwater associated with the Atacama Salt Lake. MWL of local precipitations (slope of 8.15) together with the groundwater MWL are presented. Figure taken from Boschetti et al. 2007.

To the east part of the *pampa* it is possible to find salt lakes such as Pintados, Bellavista and Llamara recharged by the groundwater system. Formation of salt lakes is related to a high evaporation rate together with the presence of groundwater close to the surface. At this point the groundwater increases in salinity considerably, in contrast to the groundwater present closer to the Andes (Aravena, 1995). In the western part of the Pampa, groundwaters are mainly freshwater, available for the consumption of animal and humans in the springs and oases (Aravena, 1995).

One of the main oases of *Pampa del Tamarugal* is Pica, located 90 km from the coast, close to the foothills of the Andes at 1200 masl. The Pica oases show an important spread of vegetation and allow agricultural activities thanks to the presence of freshwater springs (Magaritz et al., 1990; Aravena, 1995). These springs are associated with the fracture network known as *Altos de Pica* formation located in the highlands of the Andes Mountains (Figure 2.8). Thanks to this fracture, groundwater ascends to the surface forming the freshwater spring in the low valleys (Magaritz et al., 1990). Pica is known for having very fertile soil where agricultural activities have been successfully practiced since 2000 years ago (Núñez, 1984).

Stable oxygen isotopes analyses of groundwater and springs of *Pampa del Tamarugal* have shown that in general the values observed are variable (Magaritz et al., 1989; Magaritz et al., 1990; Aravena, 1995). The isotopic values for $\delta^{18}O$ of *Pampa del Tamarugal* groundwater range widely, from -13.4‰ to -3.8‰ (SMOW) (Figure 5). The most negative values are from the water samples of the Pica oases (Figure 5), while the most positive values are found in the north part of the Pampa (Magaritz et al., 1990; Aravena, 1995). These values reflect the mean isotopic composition of the precipitation or rainfall in the recharge areas of the aquifers and springs, after being affected by evaporation process that lead to an enrichment in ^{18}O (Aravena, 1995). The variability observed in the groundwater and springs of the *Pampa del Tamarugal* suggests different origins for the aquifers. There is hence a multiaquifer system.

Even though the values of the groundwater system are enriched in ^{18}O compared to the Andes rainfall, their values are still relatively low (-13‰ to -9‰), especially for the Pica Oases. This would be suggesting a recharging source for the Pica spring waters coming from higher altitudes in the Andes Cordillera.

It is worth mentioning there is no information available on oxygen isotopes from the few springs present by the arid coast of the Atacama. However, since these springs come directly from the groundwater system, it is expected the values would be similar or higher (due to evaporation process) to those from the groundwater.

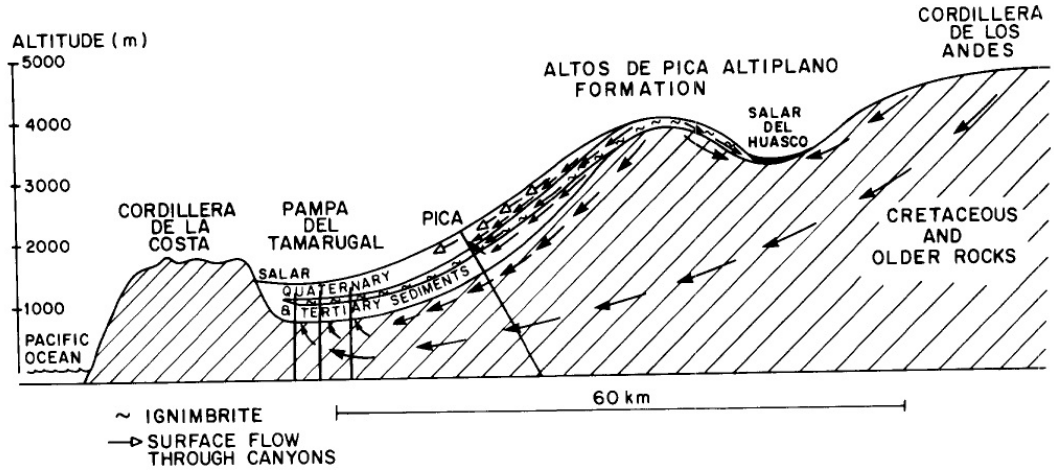


Figure 2.8. Groundwater circulation from the Andes Corilldera to Pampa del Tamarugal, including the Pica oases.

2.4.2 *Atacama Salt Lake, Atacama oases and Loa River*

Salt lakes are complex systems with high evaporation rates (Ortiz et al., 2013). The main and biggest salt lake present in northern Chile is the Atacama Salt Lake (22º lat S), at 2400 masl. Associated with the salt flat of Atacama are different aquifers and lagoons (such as Puilar, Chaxa and Barros Negros) that support various ecosystems (Ortiz et al., 2013). The recharge of the salt lake comes from precipitation occurring at the high Andes from rain and snow-melt. The amount of rainfall in the Atacama salt lake is approximately 10 to 25 mm/year (Ortiz et al., 2013).

Oxygen stable isotope analysis carried out in the waters of the salt lake, as well the groundwater associated with it, have shown a wide range of values between -8‰ and -4.1‰ (SMOW) (Aravena, 1995, Boschetti et al., 2007; Ortiz et al., 2013). The lagoons present in the Atacama salt flat are located closed to the saline deposits, such as Chaxa and Barros Negros, showing high $\delta^{18}O$ values for their waters around -0.8‰ (SMOW) (Boschetti et al., 2007; Ortiz et al., 2013).

To the north of the salt lake the San Pedro and Vilama Rivers, together with the Atacama Oases can be found (Aravena, 1995; Boschetti et al., 2007; Ortiz et al., 2013). The San Pedro River, next to the Atacama Oases where most of human occupation occurred in the past shows $\delta^{18}O$ values around -7‰ (Boschetti et al., 2007).

The Loa River is the most important river of northern Chile. Its origins are at the high altitudes of the Andes, in particular at the Miño Volcano (Aravena and Suzuki, 1990), and it is the only river at the bottom of the *Pampa del Tamarugal* that actually reaches the ocean. The main tributaries of the Loa are the San Pedro and Salado Rivers (Aravena and Suzuki, 1990). Together with carrying waters from melted snow and precipitation from the Andes, the Loa River receives the input of the two rivers mentioned before as well as groundwater of different origins. These different tributaries affect the oxygen isotopic composition together with evaporation. The values for oxygen isotopes along the Loa are between -11.2‰ and -6.2‰ (SMOW) (Aravena and Suzuki, 1990). The most depleted in ^{18}O waters are from areas in the upper course of the river, above 3000 masl, where the river begins. However, the values change along the upper course of the river, in the Alto Loa area (still above 3000 masl) with -9.0‰ in Toconce, -6.3‰ in Caspana and -7.5‰ in Ayquina (Aravena and Suzuki, 1990).

2.5. Implications for the application of stable isotope analysis in the Atacama Desert for human mobility and palaeodietary studies

Each of the ecological zones previously described present particular characteristics as well as specific isotope compositions for the associated resources. Based on this information, it is expected that diets associated with C_3 and C_4 resources (wild plants and crops) will be related to coastal, valleys and pre-cordilleran environments, contrasting to the highlands were C_3 plants dominate the vegetation coverage (wild plants and crops). Even though the wild C_4 plants are not suitable for human consumption, these could be ingested by herbivores that could potentially be hunted and consumed by humans. Differences in the isotope nitrogen composition of plants are also expected between the lowlands and highlands (Evans and Ehlerginer, 1994; Díaz et al., 2016). However, this difference does not distinguish between coast, valleys and pre-cordillera, since the plant and terrestrial $\delta^{13}C$ and $\delta^{15}N$ values tend to overlap (Evans and Ehlerginer, 1994; Díaz et al., 2016). Because of the enrichment in ^{13}C (including C_3 plants – Ehleringer et al., 1998) and ^{15}N observed in the lowland vegetation, herbivores are expected to show also higher $\delta^{13}C$ and $\delta^{15}N$ values (Figure 2.9). In contrast, vegetation and fauna in the highlands should present a composition with lower carbon and nitrogen isotope values

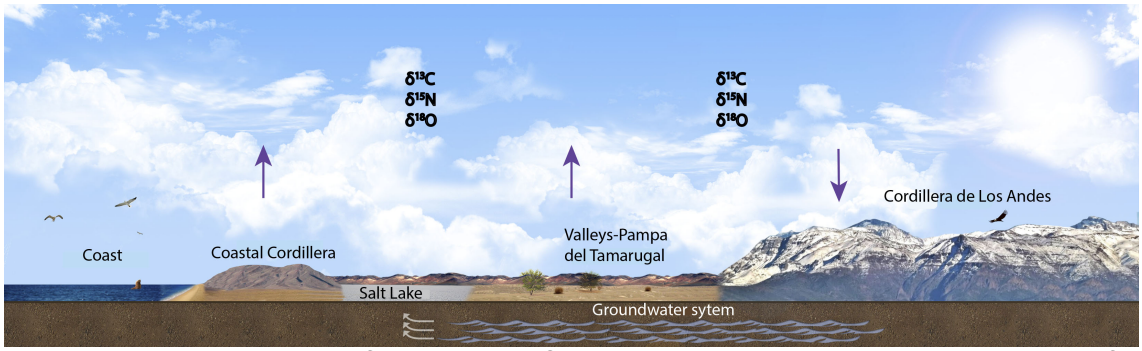


Figure 2.9. Ecological zones from northern Chile and the isotopic compositions expected for each area. Higher $\delta^{13}C$, $\delta^{15}N$ and $\delta^{18}O$ values are expected for the coast and valleys while more negative values are expected for the highlands.

These differences should have an impact on the human dietary composition, enabling lowland versus highland diets differences to be distinguished. It is also expected to identify coastal diets due to the particular enrichment in ^{15}N observed for the marine fauna. However, the possible use of fertilisers on crops, especially seabird guano could potentially affect this interpretation. Further complications might occur if there is a combination of both variables (marine diet and use of fertilisers).

The abovementioned information also shows the high complexities of the Atacama's hydrological system (Magaritz et al., 1989; Magaritz et al., 1990; Aravena and Suzuki, 1990; Aravena. 1995; Aravena et al., 1999; Boschetti et al., 2007; Ortiz et al., 2013). The complex system of groundwater and springs, including its limited and exclusive recharge sources coming directly from the Andes highlands, and the mixture of waters in the aquifers and rivers with groundwater, lead to very variable $\delta^{18}O$ values in the Atacama Desert. The main problem here is the considerable overlap of values in the potential drinking water sources for humans in the past. For instance, the values between the upper, middle and lower course of the Loa River (-11‰ to -6.3‰) (Suzuki and Aravena, 1990) overlap with the values observed for the San Pedro River (-7‰) (Boschetti et al., 2007) and in part with the Pica oases springs (-13‰ to -9‰) (Aravena, 1995). Here, the Pica oases groundwater and springs show the most depleted in ^{18}O waters due to its recharge coming directly from high elevations in the Andes (Aravena, 1995). As mentioned by Aravena et al. (1999) the main differences in the oxygen isotope composition of precipitation and groundwater is between high elevations (above 3000 masl) compared to low elevations (below 3000 masl). Aravena et al. (1999) mention that waters depleted in ^{18}O have also been reported for the Bolivian *altiplano*. Thus, oxygen isotopes present a serious limitation, being difficult to identify individuals consuming water in the lowlands. The differences could only be observed when comparing lowland versus high elevation water sources, following a

similar pattern to the one for carbon and nitrogen isotopes (Figure 8). Hence, lower $\delta^{18}O$ values will be expected for populations inhabiting the lowlands in contrast to the Andes Mountains.

All the aspects discussed here will be considered and evaluated in the interpretation of the isotopic values obtained for flora, fauna and ancient human remains, in Chapters 4, 5, 6 and 7.

Chapter 3

The Late Intermediate Period in the Atacama Desert

This chapter will present more details on the mobility models for the LIP previously mentioned in Chapter 1. At the same time, a description of the sites, material cultural and economical activities of the three cultural groups studied in this thesis will also be given.

3.1 The mobility models for northern Chile during the LIP: Limitations, gaps and new perspectives

Societies during the LIP, despite the lack of a centralised state system, maintained a high level of social complexity and were probably quite hierarchical having status differences (Uribe, 2006). The LIP represented a period of local development in which the basic social structure was represented by the *ayllu*, somewhat analagous to clans. The *ayllus* were based on strong social relations of reciprocity and redistribution between individuals (Uribe, 2006; Nielsen, 2009; Torres-Rouff and Hubbe, 2013). Following the basic Andean ideals of complementarity, reciprocity and redistribution (based on ethnohistorical and ethnographical antecedents – Schippacasse et al., 1989) shared by the *ayllus*, the exchange and trade of objects/food resources together with high mobility patterns have become the main aspects characterising the LIP (Schiappacasse et al., 1989; Núñez, 1984; Uribe, 2006; Nielsen, 2009).

The interaction between individuals would begin at the *ayllu* level but then it would expand to greater dimensions, involving different neighbour communities until reaching finally the contact between distinct (and also geographically distant) cultural groups or entities (Uribe, 2006; Nielsen, 2009). The *ayllu* structure of social organisation persists today in the Andes. The Spanish chronicles gave detailed descriptions on how the *ayllus* worked during their arrival to the Central and South Central Andes (Nielsen,

2009). For this reason, the amount of ethnohistorical documents describing this type of organisation is considerable, and it has been deeply studied during the last 40 years (Murra, 1972; Van Buren, 1996; Martínez, 1998; Berenguer, 2004). These documents have had a great impact in the archaeological studies, especially for the Inka Empire and also the LIP. Based on these antecedents, Murra (1972) proposed his classic theory on the "maximum control of vertical archipelagos". Given the particular geography that characterises the Andes (coast, valleys, highlands and *altiplano*), the groups inhabiting the different ecological zones could exchange complementary products. For instance, *altiplano* people might access to maize from the lowlands in exchange for potatoes. He proposed that these 'archipelagos' were colonies under the control of *altiplano* communities and therefore had direct access to and control of the resources they lacked. By directly controlling the exchange, through the presence of colonies, mobility and interaction between the lowland ethnic groups was almost nonexistent (Nielsen, 2009). This mobility model has been by far the most popular, and has been used to explain contact and interaction during historical times in the Andean region. The model was also applied to the Inka, which immediately followed, as well as to the post-Conquest period. In fact, the characterisation of the LIP was reconstructed almost entirely based on the Murra model for the Central and South Central Andes during the 1980s (Schiappacasse et al., 1989).

Browman (1980) presented a contrasting "*altiplano* model", which argued that no colonies were present in the Andes, but rather that the *altiplano* groups formed networks in order to exchange objects and products. The trade would have occurred through the use of llama caravans. Núñez and Dillehay (1995), combining both models, then suggested that interaction occured in rather a different way for the South Central Andes. This model covered the territories from south of the Titicaca basin to Copiapó in northern Chile, including the northwestern Argentinian valleys as well as the Oriental side of the Andes (jungle-Amazon) (Núñez and Dillehay, 1995). The "gyratory

mobility" model of Núñez and Dillehay implies that specialist agro-pastoralist groups controlled the trade of objects between the ecological zones. These authors base their proposal on the importance of llama caravans and their carrying capacity for mobility in the Andes. The travels could last for more than a week to one or two months, always stopping in logistic sites for rest, water and food. The caravans would have moved between settlements located in different places. Hence the travels would have included movements in the following order: highland-highland; highland-coast; and highland-jungle (Berenguer, 2004). It differs from the *altiplano* model too, by suggesting the direct exchange between communities did not occur, because the specialised agro-pastoralist groups were in charge of what was effectively, trade (Núñez and Dillehay, 1995).

This model contrasts with the vertical archipelago in a way that is neither centralised nor hierarchical but rather egalitarian (Berenguer, 2004). Proponents emphasize that the settlements to which the caravans were travelling (in the different ecological zones) needed to be relatively egalitarian otherwise it would cause disequilibrium in economic interactions and reciprocity (Núñez and Dillehay, 1995; Berenguer, 2004).

Núñez and Dillehay (1995) state that gyratory mobility could be identified in the archaeological record when non-local objects are present in the residential sites or cemeteries. They would be a clear reflection of the llama caravans in the visited sites, telling about interaction between the local communities and the pastoralists.

Even though this model proposes a more flexible explanation for contact and trade for the LIP, it leaves many questions unanswered. First, it is not clear to which groups (*altiplano* or highland), the specialised agro-pastoralist groups belong, or whether they are rather independent mobile *caravaneros.* Further, it is not explained how might they have interacted with the different local communities (Berenguer, 2004; Nielsen, 2009). There are contradictions in the possible interaction the caravans had with the altiplano

colonies. It is not specified if the caravans collaborated with the exchange of resources between the colonies complementing them, or if they were independent, especially for the LIP. There are contradictions here, as Núñez and Dillehay (1995) themselves acknowledge, there was not a direct control of the vertical zones, yet they suggest that for later periods the *altiplano* groups had gyratory mobility and colonies regulating the trade (Berenguer, 2004). In addition, the merely presence of foreign objects in a local site does not imply the individuals were actually inhabiting there.

Apart from these flaws, all these models concentrate exclusively on the *altiplano* or specialist pastoralist communities of the highlands as the active participants, leaving the lowland communities as passive recipients, inactive in the exchange network of contact and mobility. Even though different theories have discussed mobility patterns *along* the Pacific coast (Bittman, 1983), not many proposals exist to explain the inland movements of coastal people. In fact, it is usually assumed that *altiplano* and/or inland groups contacted the coastal groups, and not on the other way around. Pimentel (2012) argues coastal communities tend to be left behind and not considered regarding mobility and interactions with the interior. Following this, Pimentel (2012) raises an important point by suggesting how mobility between valley populations occurred, as well as for the coastal groups. Based on the study of archaeological caravan routes, together with logistic "inter-nodal" sites (sites where the travellers would stop to rest and eat) and geoplyphs in northern Chile, Pimentel (2012) suggests two types of mobility patterns. The first one is described as *caravan mobility* that would characterise the inland connections between the oases of the Atacama Desert. Inter-nodal sites between the oases supports the use of llama caravans based on the considerable evidence of logistic sties in the routes. At the same time, these sites do not show evidence of a stable occupation through time, but rather a place to stay over the night or a couple of days during the travel. These sites show evidence of llama dung, food items, pottery and ritual objects. Not surprisingly, the ritual objects such as mineral

copper were offered to the ancient Andean deities (including the earth, the mountains) for good fortune during travel (Pimentel, 2012). Because of the dry conditions of the Atacama, it is still possible to distinguish the routes followed by the caravans, as they are associated with, or close to, the logistical sites. In addition, many geoglyphs are found next to the routes and inter-nodal sites, being quite visible even from long distances (Briones et al., 2005; Pimentel, 2012).

The second type of mobility pattern is the *coastal mobility*, in which individuals from the Pacific shore would have walked to the interior, following specific routes in order to get raw material for the manufacture of fishing-tools. The sites associated with the coastal routes are simpler compared to those in the interior and do not show evidence of llama caravan use (Pimentel 2012).

Even though Pimentel (2012) gives new insights on the mobility patterns during the LIP for the Atacama Desert based on the archaeological evidence, the study is still too concentrated on the materials involved in the exchange itself. Questions remain regarding whom were the people moving and why they moved. In addition, the social connotations of these individuals and their relations with the local communities are still not clear.

Pimentel's work on the inter-nodal sites together with Nielsen's ethnographical research (2009) has provided new perspectives on the mobility patterns for the area in the past. These approaches have aimed to contrast the archaeological evidence with the classic mobility models of Murra (1972) and Núñez and Dillehay (1995). However, there is a predominant tendency in these studies to evaluate the archaeological evidence under the scope of the gyratory mobility or vertical archipelago models, until today. The LIP evidence in most of the cases has been forced to fit the models based on either the presence of *altiplano* colonies in the lowlands or specialist *caravaneros* controlling trade.

Noticeably, the archaeological studies are still heavily influenced by the ethnohistorical documents. As suggested by Adán et al. (2004) Northern Chile's archaeology has been reconstructed under a "historical disdain", especially for the LIP. Changes in the regional archaeology research started during the mid-1990s onwards, focusing on the study of northern Chile's prehistory from a local perspective (Agüero et al., 1997; Agüero et al., 1999; Adán et al., 2004; Uribe, 2006). This was done in order to better understand the LIP local dynamics, inside and between the cultural groups, leaving aside the fixation to the classical mobility models. Interesting aspects have emerged from this research. For instance, there is a clear and strong display of cultural identity in each cultural group of the Atacama Desert (Agüero et al., 1997). The Atacama-Alto Loa cultural group together with the Tarapacá and Antofagasta cultural groups stands out in their local developments in the LIP. Each of these groups shows particular characteristics that contrast with the mobility models presented above. In addition, so far no evidence of colonies has been found in the archaeological record of these cultural groups (Agüero, 1997; Adán et al., 2004; Uribe 2006).

In the following section a description of the Atacama-Alto Loa, the Antofagasta and the Tarapacá cultural groups is given.

3.2 Cultural groups in the Atacama during the LIP

3.2.1 The Atacama-Alto Loa cultural groups

The LIP in the Atacama oases (Figure 3.1) has largely been defined as a moment of decline and cultural impoverishment (Costa-Junqueira, 1988; Schiappcasse et al., 1989; Uribe et al., 2004; Knudson and Torres-Rouff, 2009; Uribe, 2012). During the Middle Period of Tiwanaku influence, many metal (gold and copper) and wooden objects (vessels and tablets for hallucinogen consumption) as well as pottery and textiles were abundant in the burial offerings (Núñez, 1995). However, the situation changed during the LIP. The cemeteries do not show the same wealthy offerings

observed for the Middle Period, having fewer metal objects and “simpler” types of pottery (Costa-Junqueira, 1988).

Nevertheless, the LIP in the Atacama oases shows new cultural dynamics that led local populations to be in closer interaction with the highlands and *altiplano* communities from southern Bolivia and northwestern Argentina (Uribe et al., 2004; Uribe, 2012). Here the populations inhabiting the Alto Loa region in the upper course of the Loa River (highlands) had an important role, mixing local Atacama Oases traditions with those of the *altiplano*. The Alto Loa is located above 3500 masl, in the pre-cordillera and *quebrada* regions, that can be described as the highlands (different to the *altiplano* located mainly in Bolivia above 3800 masl). The Atacama Oases and the Alto Loa region are approximately 100 km distant from one another. In this way, the Atacama Culture for the LIP included the closed tradition of the Atacama Oases and the Alto Loa.

The Atacama Culture tradition of inhabiting the Atacama oases changed around AD 1100-1350, when the Alto Loa territories were occupied. They included sites in locations such as Turi, Toconce and Caspana. Prior to this, the Atacama Culture tradition was was strongly based in the oases (Uribe, 2012).

The *altiplano* influence in the local LIP populations (Atacama oases and Alto Loa) is clear by the building of typical *altiplano* structures such as *chullpas* (Schiappacasse et al., 1989; Uribe, 2012). These were used for food storage but also as funerary sites. Chullpa structures can be found in the sites of Catarpe Oeste in the Atacama oases and Toconce and Turi in the Alto Loa region. However, it is noteworthy that *chullpas* did not replace the local funerary practices of the Atacama Culture, based on burials in the ground marked by stones. Instead, both traditions co-existed in the oases and highlands (Uribe, 2012).

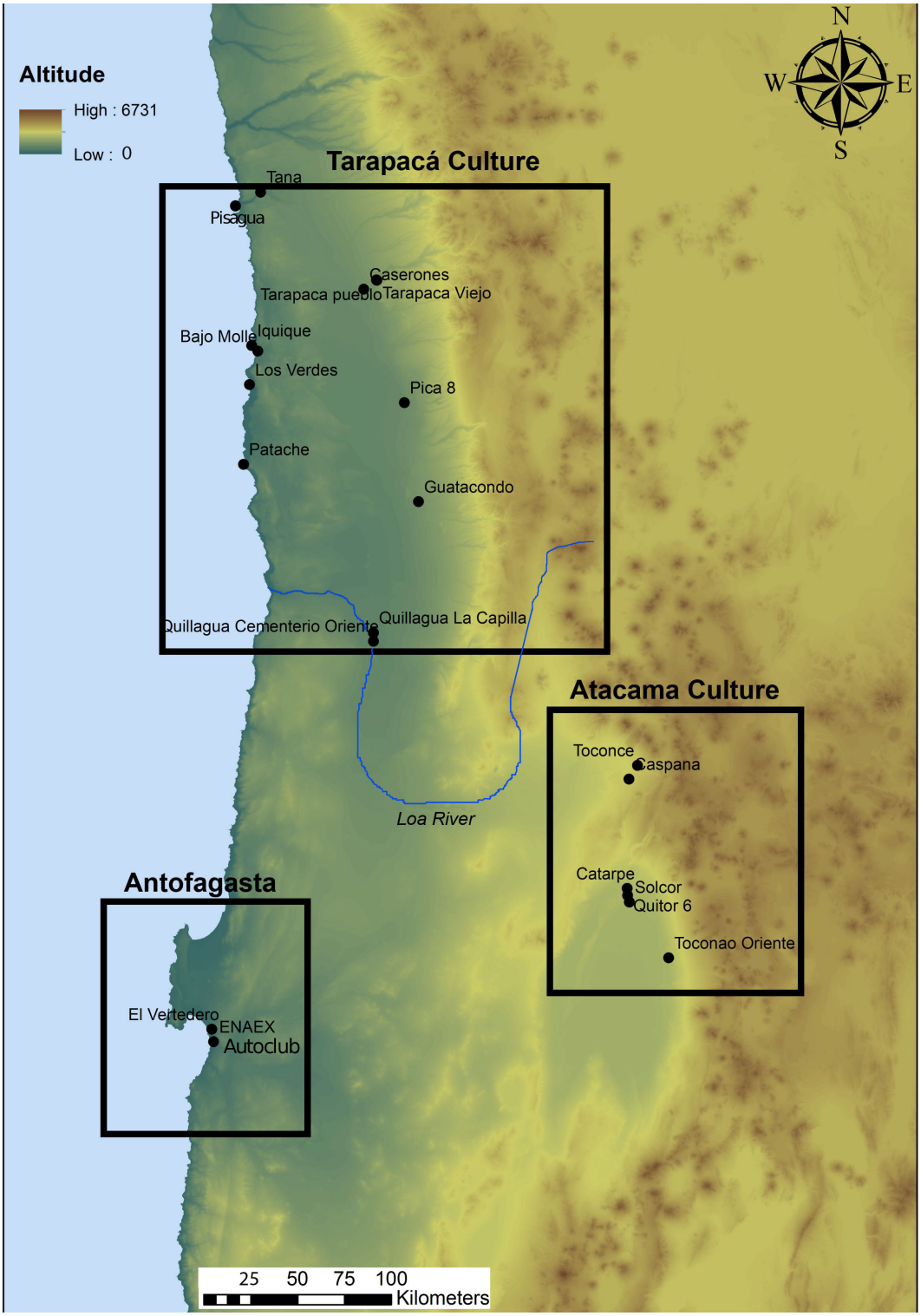


Figure 3.1. Map of northern Chile and the study area. Cultural groups are shown inside the squares. Sites for each cultural group are presented in black dots.

Considering the hybrid traditions of the Atacama oases and the Alto Loa highlands, local pottery and textile types have been defined for the area. The Atacama oases pottery types are known as Aiquina, Dupont and Rojo Violáceo (Agüero, 1997; Uribe,

2012) (Figure 3.2). At the same time, local Alto Loa pottery types remain frequent in these two areas, being defined as Turi Rojo Alisado, Turi Rojo Bruñido, Turi Gris Alisado. *Altiplano* pottery types are also found in the Atacama oases and Alto Loa. However, there is a clear predominance of the local traditions in each case.

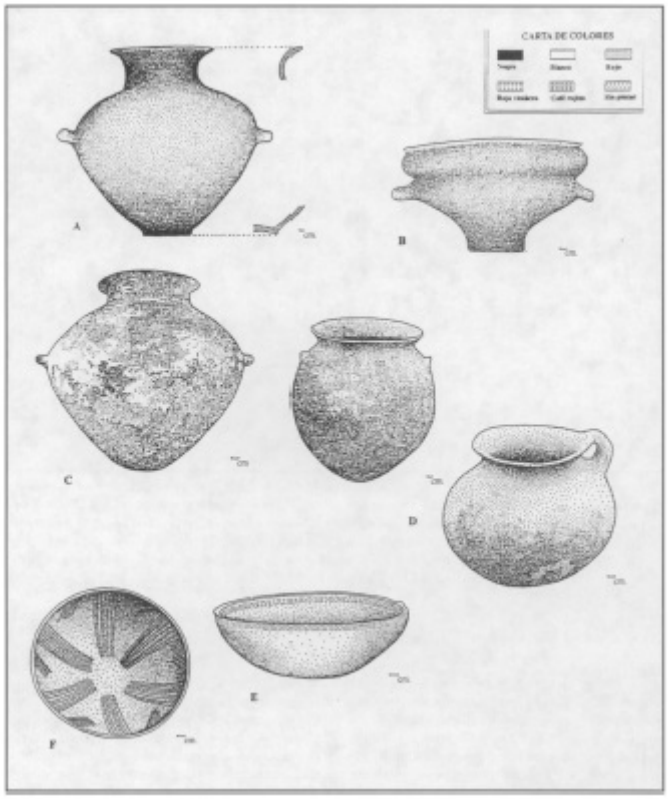


Figure 3.2. Local Atacama-Alto Loa pottery types including pots and plates (Agüero et al., 1997). Image not scaled.

Textiles also show particular Atacama Culture styles. Tunics and shirts show square-rectangular shapes with straight warp borders (Agüero et al., 1997) (Figure 3.3). Textile bags including medium size bags and sacks (usually loaded on camelids for transport) show stripped decorations (Agüero et al., 1997).

Even though there is a clear *altiplano* influence in the Atacama oases and Alto Loa region, the archaeological evidence has been taken as suggesting a strong local component influenced by the altiplano communities but neither dominated nor controlled by them (Uribe et al., 2004; Knudson and Torres-Rouff, 2009). As such the

altiplano-highland and Atacama Oases mixed their traditions, sharing cultural aspects, but retained distinct local identities.

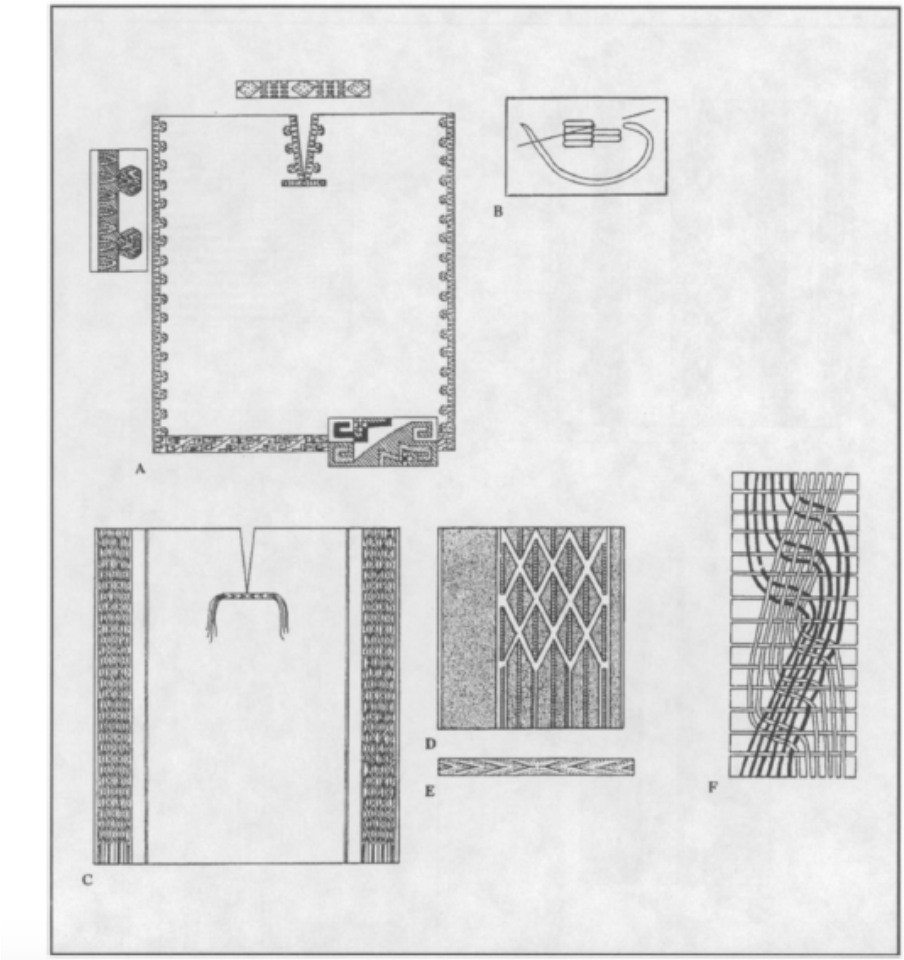


Figure 3.3. Local Atacama-Alto Loa textile types (Agüero et al, 1997). Image not scaled.

During the LIP in the region, agricultural activities reached high levels of specialization. In the case of the Atacama Oases agriculture activities were carried out next to the rivers San Pedro and Vilama (Núñez, 1995). Irrigation canals were also built in the Oases for watering agricultural fields not located immediately next to the river sources (Núñez, 1995). Systems of agricultural terraces are frequent, especially in the highlands-Alto Loa (Uribe, 2012). Production of maize, squash, beans and other crops was quite relevant in the region and was the main subsistence activity together with

pastoralism. However, this was always complemented by wild fruits such as *algarrobo* (*Prosopis algarrobo*) and *chañar* (*Geoffroea decorticans*).

Zooarcheological evidence suggests there was a heavy reliance on camelid protein (Núñez, 1995; Uribe et al., 2004). This was complemented with the consumption of small rodents (there being little other mammalian game in the region). In contrast to the Tarapacá Culture, camelids were consumed with greater frequency in the Atacama region together with their use for the production of textiles and transport (Schiappacasse *et al*., 1989).

Coastal evidence in the Atacama oases and Alto Loa is scarce. Both areas are approximately 200 km away from the coast. When present, the marine evidence is restricted to shells used for beads or small containers (Núñez, 1984; Núñez, 1995; Uribe et al., 2004). Thus, the subsistence practices of the Atacama Culture were probably based exclusively on terrestrial resources.

3.2.2 The Antofagasta maritime tradition

The LIP groups inhabiting the coast of Antofagasta (Figure 3.1) followed a marine tradition that finds its roots in early northern Chile prehistory (Ballester and Clarot, 2014; Andrade et al., 2015). No “Cultures” or “Cultural Complex” such as the Tarapacá and Atacama, have been suggested for Antofagasta, probably due to a lack of research in the area. However, recently several new studies have provided insights on the cultural traditions of the coastal groups (Ballester at al., 2014; Ballester and Clarot, 2014; Clarot et al., 2014; Clarot et al., 2014-2015). The archaeological evidence comprising fishing-related material culture, including hooks, fishing sinkers (made of rocks) harpoons, spears, seal bones and leather (used for raft construction) as well as whale bones for building structures (Ballester and Clarot, 2014), shows a strong dependence on coastal subsistence. Inland contacts are, however, inferred from the presence of pottery and textiles as burial offerings, and wooden tables for hallucinogen

consumption, although the frequency is low. During the LIP this connection intensified (Clarot et al., 2014-2015). It is not clear yet which groups were in contact with the coastal communities of the Antofagasta region.

3.2.3. The Tarapacá cultural groups

Communities of these cultural groups occupied the driest area of the Atacama Desert (Figure 3.1), including the arid coast, *Pampa del Tamarugal* and pre-cordillera areas. In each of the geographical zones related to the Tarapacá Culture, different economic specializations were developed intensively. In the coastal region, fishing, hunting and collection of marine resources occurred, following millennia-long traditions (Núñez, 1984; Uribe, 206); while an intensification of agriculture and pastoralist activities occurred in the valleys, highlands and *altiplano* (Núñez, 1984; Uribe, 2006). These specializations contributed to the exchange of resources between the different groups, generating systems of economic complementarity (Moragas, 1995; Uribe, 2006).

The Tarapacá groups show a clear pattern in their material culture. Specific types of pottery and textiles have been described, defined by a strong local component. The Pica-Tarapacá pottery types (Agüero et al., 1997; Uribe et al., 2007) characterising the LIP are: Pica Charcollo, Pica Chiza and Pica Gris Alisado (Figure 3.4). These types are mainly monochrome showing different shapes such as containers, bottles, plates and vessels, as well as anthropomorphic and zoomorphic pots. The presence of these pottery types in inland sites is considerable (Agüero et al., 1997; Uribe, 2006; Uribe et al., 2007). These pottery types are found in the entire Tarapacá Culture “territory”, from Camiña to the Loa River (Aügero et al, 1997). In addition, these types have been found in the Arica region and the Atacama Culture areas, but in lower frequencies.

Tarapacá textiles also show a marked local style in their shapes, colours and designs (Agüero 2006). The tunics and shirts of the Tarapacá Culture show semi-trapezoidal

shapes with curved warp borders (Figure 3.5). Decoration is observed in the lateral sides of the shirts, as polychrome lateral stripes. The textile types did not only include personal clothes but also ceremonial bag for carrying coca leaves known as *chuspas* and transport bags (attached to and carried by camelids) known as *talegas* (Agüero et al., 1997). These textile types are common to the entire Andean region. However, the styles and decoration patterns provide the local cultural imprint.

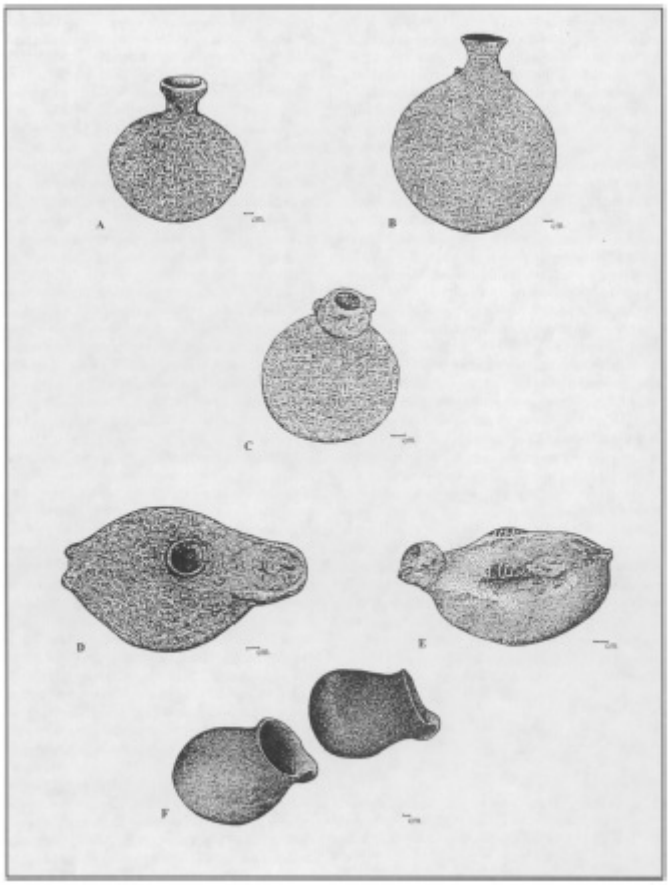


Figure 3.4. Local Tarapacá Culture pottery including anthropomorphic and zoomorphic types (Agüero et al., 1997). Image not scaled.

The Tarapacá culture shows connections to the coast, although the nature of contact occurred it is still not clear. Moragas (1995) described the Tarapacá coast occupations based in their maritime traditions. The cemeteries at the coast present abundant marine evidence in the form of shell middens and the remains of fish, marine birds and

sea mammals. These coastal resources were consumed but also used for the manufacture of fishing equipment, seal-leather rafts (in the absence of trees suitable for wooden rafts or canoes), and shell containers for pigments and hallucinogenic powders (Moragas, 1995). The main cemeteries with Tarapacá occupations in the coast are: Los Verdes (Sanhueza, 1982), Bajo Molle (Moragas, 1995), Pisagua (Agüero, 1995; Adán et al., 2004); Patillos (Moragas, 1995); Patache (Moragas, 1995); and Caleta Huelén (Núñez, 1984; Moragas, 1995). Pisagua represents the northern boundary of the Tarapacá Culture. Here, inland textiles have a strong presence. This has been interpreted as a strategically control of the coast by inland Tarapacá groups, in order to access marine resources (Agüero, 2006) and impose the local Tarapacá tradition in a cultural boundary location (boundary to the north with the Arica cultural groups). A very high frequency of marine resources is observed at this site, especially mussels, fish, sea mammals, and birds. These resources may have been preserved and accumulated for exchange – possibly for textiles and maize with people from the interior (González 2006).

The inland presence on the coast of Tarapacá is strong, as suggested by the burial offerings (Moragas, 1995). These show pottery, textiles and food products associated with the valleys such as Pica Charcollo pottery, Tarapacá textile styles, and crops and fruits (i.e. maize, squash, *algarrobo*), showing considerable inland evidence in the coastal cemeteries.

Following the classical interpretations for the LIP, Moragas considered the presence of inland objects by the coast as a direct reflection of valley colonies, ultimately controlled by the *altiplano* communities (1995). Her interpretations were reinforced by the presence of an inland individual in the Bajo Molle cemetery, known as "*El Señor de Bajo Molle*"[1] (The Lord of Bajo Molle) (Figure 3.6). This adult male was buried wearing a seal leather helmet, decorated with wool and flamingo feathers, as well as a quiver

[1] Although he has also been called *Señor de Pica* (Lord of Pica)(Sepúlveda et al., 2014)

(*carcaj*) (Figure 5) made from fox skin, with arrows inside. In addition, the grave held a finely decorated bag (with hooks, diamonds and escalated line designs), a squash container, decorated basketry, Pica Chiza pottery and metal ornaments (Moragas, 1995).

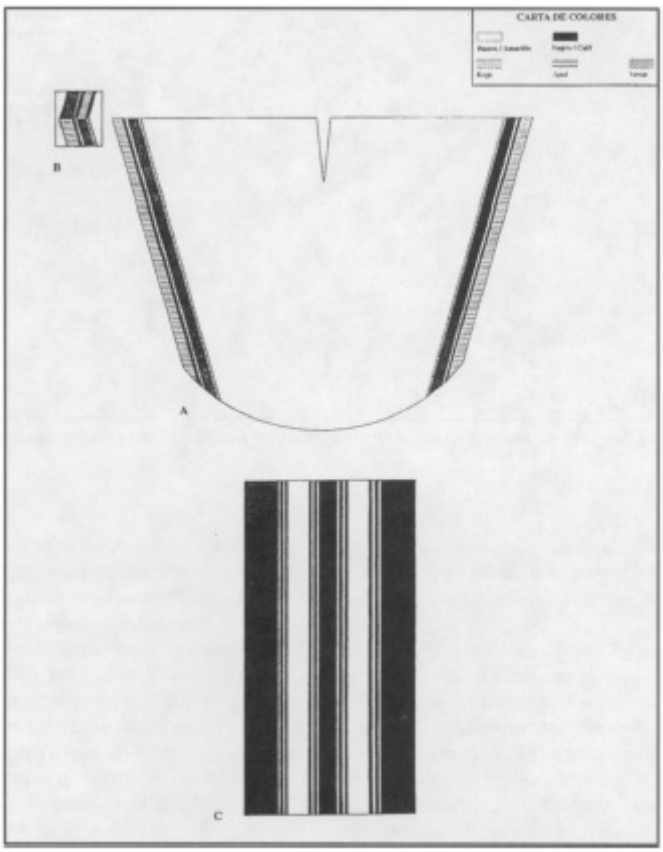


Figure 3.5. Local Tarapacá textile types (Agüero et al., 1997). Image not scaled.

Agüero (2006) suggests that most of the textiles found at the coast are not as in rich in technique, decoration and style as those observed in the interior. However, most of them are made from camelid wool. In addition, many of the coastal textiles are associated with marine activities such as bags for shellfish collection, etc. However, the presence of textiles at the coast in itself witnesses the important interactions existent between these two geographical areas.

The Tarapacá occupations in the valleys show a considerable development of agricultural activities, as suggested by the archaeobotanical evidence found in the habitational sites of Caserones (1000 masl) and Camiña-1 (3200 masl) (García and Vidal, 2006). The main crops found are maize and squash, together with beans but in less frequency. There was also collection of fruits such as algarrobo (*Prosopis* sp.), chañar (*Geoffroea decorticans*) and molle (*Schinus molle*) (García & Vidal, 2006; Uribe, 2006).

The Camiña-1 site shows a complex system of terraces for the cultivation of crops (García and Vidal, 2006). The evidence supports an emphasis on maize agriculture. In addition, *quínoa* (coming from the altiplano), *algarrobo* seeds and squash were also found here. At this site, plant resources were not only used for consumption but as fodder for camelids and fire making (García and Vidal, 2006). A substantial amount of maize and other crops such as potatoes and *quinoa* were also found in the Pica 8 cemetery (Núñez, 1984).

The zooarchaeological evidence consists mainly of camelids and rodents. However, most of the camelid evidence corresponds to coprolites and hair associated with the use of these animals for textile production and transport instead of meat consumption (Uribe, 2006). In addition, coastal evidence in inland sites is very frequent (Núñez, 1984; González, 2006; Uribe, 2006). Remains of fish, mussels and birds from the Pacific coast were found in the Caserones village as well as in the Pica 8 cemetery, supporting the interaction between these two areas (González, 2006; Uribe, 2006).



Figure 3.6. Skull and helmet of the *Señor de Bajo Molle* (Lord of Bajo Molle) (Pacheco et al., 2016).

The Pica 8 cemetery dating to AD 900-1030 (Uribe et al., 2007), is the “type site” for inland Tarapacá, located 90 km away from the coast in the Pica oases. Núñez excavated the site in 1964, dividing it arbitrarily in sectors (A–E and G–I) (Núñez, 1984). Núñez (1984) has suggested the presence of strong connections between Pica 8 and foreign groups coming from different regions, including the coast, the *altiplano* and other eastern tropical regions. These interpretations are based on the wide variety of offerings found at the site, including impressive amounts of maize, different types of weapons, musical instruments and even tropical birds (*Ara ararauna*) (Núñez, 1984; Zlatar, 1984). The economy of Pica was based on agricultural activities together with the production of pottery and textiles (Uribe, 2006). Nevertheless, it is likely that important trade and caravan movements operated from the oasis to the coast and vice versa. Many transitory campsites between the Pica oases and the coast have been

found along the Atacama Desert following routes marked by the presence of geoglyphs associated with the Tarapacá Culture (Briones et al., 2005).

These routes and associated geoglyphs can be found all along the Tarapacá Culture ”territory”, as well as for the Atacama Culture. It is remarkable that even the geoglyphs show an association with the Tarapacá Culture styles (Briones et al., 2005; Pimentel, 2012). In fact, anthropomorphic figures in the geoglyphs are depicted wearing textile tunics ant shirts with the trapezoidal and curve borders types of Tarapacá (Pimentel, 2012).

The presence of these routes as well as geoglyphs can be tracked down to the Loa River, reaching the Atacama Culture boundaries by the Alto Loa region. In the Lower course of the Loa River, the Quillagua oases represent a particular sector of cultural encounter. Here, the habitation site La Capilla (Agüero et al., 1997) as well as the Cementerio Oriente, show evidence associated both with the Tarapacá and Atacama Cultures. It is suggested these oases acted as a place where both cultural groups peacefully co-existed and interacted (Agüero et al., 1999; Pimentel, 2012).

It is worth noting that the grave goods found in Cementerio Oriente show food resources such as maize (*Zea mays*), *algarrobo* (*Prosopis sp*.), *quínoa* (*Chenopodium quínoa*), dry fish, squash; pottery; textiles; and trays and tubes belonging to the hallucinogenic complex (Latcham 1933; 1938). In this sense, Quillagua probably had intense connections with the coast (70 km away from the oasis).

3.3. The Study Sites

As described previously, the mobility models do not explain clearly how people moved and interacted, and who they were. The presence of colonies or the exchange controlled by specialised agro-pastoralist groups remains questionable. The diverse cultural traditions present in northern Chile also call for a more careful approach, avoiding the imposition of general models in the Atacama Desert. Given these

problems, as well as the strong evidence of mobility and interaction for the LIP, individuals from the different cultural traditions will be studied here following an isotopic approach. Sites associated with the Atacama Culture, Antofagasta coastal groups as well as for the Tarapacá Culture (Inland and Coast) were selected for this research. A brief description for each of the sites studied here is given below.

3.3.1 *Atacama Culture sites*

- Quitor 6 (n=10 human samples): This cemetery was excavated in the 1980s (Costa-Junqueira, 1988). It was occupied during the beginnings of the LIP, with dates from AD 940-1240. The burials show evidence of local pottery (Dupont-Roja Viólacea) in most of the graves. The individuals were buried in a seated position covered by a layer of *algarrobo* seeds and pods (Costa-Junqueira, 1988) together with basketry, small squash pots (a few of them decorated), metals (mainly rings of copper and silver), wooden objects (spoons and Andean vessels known as *kero*). In two cases individuals were buried with dogs. Only two burials presented evidence of caravan activities: hooks to attach transport bags (*talegas*). The evidence of this cemetery was described as "poor" (Costa-Junqueira, 1988) compared to the previous period of Tiwanaku influence, in which burials had abundant metal objects, hallucinogen-consumption tubes and tablets, textiles, etc. The type of burials and location describe this site as still strongly associated with the oases tradition observed during previous periods despite its "impoverishment".
- Toconao Oriente (n=14 humans): Located around 12 km southwest of San Pedro de Atacama, this cemetery was excavated during the 1990s (Hubbe pers comm.) by Llagostera and Costa Junqueira. A total of 21 skeletons were recovered. Originally this site was associated with the Formative Period but radiocarbon dates for two burials gave an LIP association of AD 1053-1408

(Torres-Rouff and Hubbe, 2013). So far, nothing has been published about the burials and offerings of Toconao Oriente.

- Catarpe 1 (n=7 human samples): This cemetery is located in the Atacama oases and it was occupied during the LIP with dates between AD 1225-1422 (Torres-Rouff and Hubbe, 2013). This cemetery shows evidence associated with the LIP, showing a local pottery tradition but including now evidence from the Bolivian altiplano tradition. Lately, this cemetery had important Inka influence in its late phase of use (Torres-Rouff, 2007).
- Toconce (n=2 human samples) and Caspana (n=4 human samples): These two cemeteries are located in the upper course of the Loa River, being approximately 100 km north from the Atacama Oases at 3800 masl. This area known as *Alto Loa* shows occupations during the LIP. The evidence suggests a strong connection with the *altiplano* groups from southern Bolivia. As mentioned before it is suggested that the Atacama oases groups began moving towards the *quebradas* and highlands in order to occupy territories in the *Alto Loa* (Uribe et al., 2004). Le Paige excavated the cemeteries of Toconce and Caspana in the 1950s-1960s (again, only skulls). The pottery found at these sites show clear affinities with the local Alto Loa tradition (Turi Rojo Alisado, Turi Rojo Bruñido) and those of the Atacama oases (Dupont and some few shreds of Rojo Violáceo), as well as *altiplano* pottery (Hedionda type) (Castro et a., 1984).

3.3.2 *Antofagasta sites*

- Auto Club (n=6 human samples): Cemetery excavated in the 1970s and analysed by Costa Junqueira and Sanhueza (1976). The cemetery was located 3 km south of the town of Antofagasta. A total of 13 burials was excavated, with 22 individuals recovered during activities of consultant archaeology (Costa Junqueira and Sanhueza, 1976; Ballester et al., 2014). Evidence found in the

cemetery clearly shows its association with a marine tradition. Objects related to fishing activities were found, such as harpoons, rafts pieces made of seal leather, and oars made of cactus Wood (*Opuntia sp.*). Few pottery shreds were found at the site, and these have not been given a cultural affiliation. There were also specialised objects for hallucinogen consumption that imply contacts with the interior.

- El Vertedero (n=2 human samples): This cemetery was found next to the trash dump of Antofagasta in the year 2000. Rescue excavations recovered six burials from this cemetery dating to the LIP. As in the Auto Club site, this cemetery shows evidence of marine activities. Textiles were recovered as well as pipes for hallucinogen consumption, necklaces and beads made from shells, pottery and bone objects (Ballester and Clarot, 2014).

3.3.3 *Coastal Tarapacá Culture sites*

- Pisagua-Uhle (n=10 human samples): This collection consists only of skulls, some of which still have hair and skin preserved. Max Uhle carried out the excavations in the coast of Pisagua during the beginnings of the 20th century (Núñez, 1984). Uhle divided the different cemeteries of Pisagua according to the chronology he developed. The cemeteries C, H and A were assigned by Uhle to the Tiwanaku and the Tiwanaku-Atacameño phases following his system (Núñez, 1984). The materials found in the burials suggests they belong to the LIP. Agüero analysed the textiles from this cemetery, and they clearly show a strong connection with the Tarapacá culture (Agüero, 2006). Nevertheless, textiles from other provinces are also represented here such as textiles from the Atacama Culture, but in a lower frequency (Agüero, 2006). Agüero (2006) suggests that this Tarapacá presence in Pisagua would have

delimited the boundaries of this culture by the north. Crossing north to Pisagua, the Arica culture "territory" begins.

- Pisagua Gruta (n=3 human samples), Pisagua Hospital (n=2 human samples) and Pisagua 5 (n=1 human samples): All these sites are also located in Pisagua, but mainly come from excavations carried out during consultant activities by Moragas in the 1990s (Méndez Quiros pers. comm). They are all associated with LIP pottery and textiles of the Tarapacá culture. In addition, they show clear evidence of marine and fishing activities, with the presence of harpoons, spears, shell middens, etc.
- Los Verdes 1 (n=2 human samples), Los Verdes 5 (n=1 human samples), Bajo Molle 1(n=2 human samples), Bajo Molle Edificio Armada (n=2 human samples), Iquique (n=2 human samples), Patache Q (n=1 human samples): All these sites are located in and to the south of the modern city of Iquique. Sanhueza (1982) excavated Los Verdes sites in the early 1980s. The sites show abundant marine evidence in terms of fauna (fish, shells, marine birds, crabs, marine mamals) and fishing techonology. *Algarrobo* seeds were also found together with local coastal wild flora, specifically the species *Zephira elegans*, probably for human consumption. Similar emphasis on marine resources was found at the sites of Bajo Molle and Patache Q (Moragas, 1995). But at the same time, there are clear connections with the interior shown by the presence of pottery and mainly textiles (Moragas, 1995; Agüero, 2006). The textiles resemble the inland style, especially from Pica 8, but not in the same quality (Agüero, 2006). In addition, some of the textiles found are directly associated with marine activities, such as the collection of shellfish.
- Caleta Huelén 11 (n=2 human samples), 12 (n=2 human samples): Caleta Huelén is located next to the Loa River, exactly in the area where it reaches the coast. It has had occupation since very early times, including the Archaic and Formative Periods (Núñez, 1984). During the LIP the marine tradition is

preserved, but with increased contacts with the interior, especially with the Quillagua oases. This site delimitates the southern boundary of the Tarapacá Culture influence (Uribe, 2006). As for Pisagua, Los Verdes and Bajo Molle the marine activities are clear and intense in this area (Ballester and Clarot, 1984).

3.3.4 Inland Tarapacá culture sites

- Rescue excavations in Tarapacá town (n=2 human samples) and Pica 37 (n=2 human samples): Two skeletons were recovered during consultant activities in the town of Tarapacá, due to a road building. Unfortunately, there is not much information on the context of these burials. However, judging by the textiles and evidence collected in the Iquique museum it was possible to associate them with the LIP. The skeletons of Pica 37 were found in the Iquique museum with little information on their context but. Again, thanks to the little evidence associated with the excavation details and the few pottery/textiles found with the burials, it was possible to associate them with the LIP.
- Pica 8 (n=49 human samples): Núñez (1984) excavated this cemetery in the 1960s. A total of 254 burials were recovered. The cemetery was arbitrary divided in seven sections by letters. The burial offerings in Pica 8 are quite diverse, showing in some cases quite exotic evidence such as tropical birds from the Amazon. Núñez described one of the sectors (G) as being used for burial by *altiplano* colonies, keeping their traditions at the site. This is based on the presence of potatoes, potatoes flour (*chuño*), coca leaves, *quinoa* and llamas, but mainly because of an *altiplano*-Tiwanaku-like textile. However, the cemetery shows evidence broadly dominated by local pottery styles (Pica Charcollo, Pica Chiza) (Catalán, 2006) and textiles (Agüero, 2006). In fact, the altiplano-like textile found in sector G that led Núñez to assign this sector as a colony, was re-assessed by Agüero (2006), who concluded instead that it is

consitent with a local style. As mentioned above, previous isotopic analysis in Pica 8, also support a local diet for most of the individuals (Santana-Sagredo et al., 2015a).

- Quillagua Cementerio Oriente (n = 20 human samples): Located in the lower course of the Loa River, the Cementerio Oriente in Quillagua was excavated by Vergara (1901) in the beginnings of the 20th century (collecting only the crania). New research by Agüero et al. in the 1990s, revealed three intact burials. The evidence (pottery and textiles) found here suggests the co-existence of the Tarapacá and Atacama cultures. Isotope analysis on human remains suggests a clear link with the Tarapacá culture (Santana-Sagredo et al., 2015b). Sadly, the cemetery has been looted over the last 20 years.

Isotopic analysis and their results will be further presented and discussed in chapters 5 and 7 for dietary and mobility patterns.

Chapter 4

Stable Carbon and Nitrogen Isotopes for Plants and Animals: An isotope ecology baseline for northern Chile

As outlined in Chapter 2, the isotope composition of animals and plants vary depending on the local environment, climate and geography. Thus variation in the local resources and conditions has a direct bearing on the isotope composition of consumers. Unfortunately, information about stable isotopes on the flora and fauna of the Atacama Desert is limited. This chapter aims to provide a firmer basis for the isotope composition of modern and archaeological plants and animals for the Tarapacá and Atacama cultural areas. The objective is to establish a local isotopic baseline for the study area. A brief review of the existing data and literature will be provided, to lately continue on the sampling strategies, analyses carried out and the results for carbon and nitrogen isotopes on modern and archaeological plants and animals.

4.1. Previous research

Few studies have reported on modern plant and animal isotopic values in northern Chile (but see Tieszen and Chapman, 1992; Evans and Ehleringer, 1994; Ehleringer et al., 1998; Quade et al., 2007; Díaz et al., 2016). Most of the limited work on modern plants and animals has shown how carbon and nitrogen isotope composition is clearly affected by aridity, mean annual precipitation level and the different altitudinal gradients of the region.

In contrast to the situation in Chile, many modern isotope baseline studies have been carried out in Peru and Argentina. For instance, stable isotope analysis on modern plants have been carried out (Szpak et al., 2013) in the Mocha River Valley of northern

Peru, in the south coast of Peru (Cadwallader et al., 2012) and also in north west Argentina (Samec et al., 2015). These studies show variation in the isotopic composition of plants as a function of their geographic distribution, as might be expected. For instance, altitude and/or water availability exert an impact on the distribution patterns of C_3 and C_4 plants and on their $\delta^{13}C$ and $\delta^{15}N$ values. However, the patterns and correlations between the carbon isotopic values and the local geography vary in Peru, Argentina and Chile. A correlation between $\delta^{13}C$ and altitudinal gradient was observed in northern Chile and Peru, whereby $\delta^{13}C$ values increase at higher altitudes (Tieszen and Chapman, 1992; Szpak et al., 2013). In contrast, the dry *puna* of northwest Argentina shows no correlation between $\delta^{13}C$ and altitude (Samec et al., 2015), although the altitude gradient in northern Peru and Chile was from 0 up to 4000 masl, and in north west Argentina only from 3400 to 4300 masl.

On the other hand, a clear negative correlation was observed between altitude and nitrogen isotope composition. This observation holds for the northwestern highlands of Argentina, for northern Chile, close to the Atacama Oases between Talabre (2500 masl) and the Lejía Lake (4500 masl), where $\delta^{15}N$ values decrease from 3500 masl upwards (Díaz et al., 2016).

Regarding modern fauna in northern Chile, the work of Tieszen and Chapman (1992) is until today the most complete for the area. This research was performed in the Arica area and its surroundings, and included an altitudinal transect from 0 to 4000 masl. The authors carried out analyses on a robust sample that included terrestrial (n=85) and marine fauna (n=85) (Tieszen and Chapman, 1992). Terrestrial fauna showed relatively low values for $\delta^{13}C$, suggesting a C_3- rather than C_4-based diet. The marine fauna yielded rather surprising results, as they do not show enrichment by trophic level. For instance, fish have a higher average than seals. At the same time, the nitrogen isotope results for the marine fauna show remarkably high values of up to 22‰.

Isotopic studies in northwest Argentina on modern camelids show a clear negative correlation between the camelid diet and altitude for stable carbon and nitrogen isotopes (Fernández and Paranello, 1999-2001; Yacobaccio et al., 2009; Samec, 2014). These studies included analyses on llamas (*Lama glama*), alpacas (*Lama pacos*), guanacos (*Lama guanicoe*) and vicuñas (*Vicugna vicugna*). Camelids pasturing at high altitudes, usually above 3900 masl, show lower $\delta^{13}C$ and $\delta^{15}N$ values than those herded below that altitude. The most variable values are for llamas, since these animals will pasture at different altitudes depending on the choices made by shepherds (Yacobaccio et al., 2009). These findings can potentially provide new insights into pasture management in the past (Yacobaccio et al., 2009; Samec, 2014).

Archaeological studies on ancient flora and fauna are rare for the Atacama Desert. The one exception is a report with three values for maize and a wild plant for the site of Pisagua, with remarkably high $\delta^{15}N$ values (Aufderheide et al. 1994). A similar situation is observed for Peru and northwest Argentina. The most comprehensive study was carried out by Hastorf and DeNiro (1985) in Peru. The authors argued that the very high $\delta^{15}N$ values (up to 30‰) were a consequence of diagenesis, not giving a very detailed explanation on the type of diagenetic process that could have affected the plant. High results in $\delta^{15}N$ have also been reported for northwest Argentinian archaeological crops, specifically maize (Killian-Galvan et al., 2014). These results were explained as a possible consequence of both aridity and the use of fertilisers.

Just three publications have presented values for archaeological faunal remains in northern Chile (Aufderheide et al., 1994; López et al., 2013; Díaz-Bonilla et al., 2016). The sample sizes in most of these studies are very small, and mostly are for camelids. One study at the sites of Tulán 54 and 58 (López et al, 2013) situated close to the

Atacama Oases showed considerable variability in $\delta^{13}C$ and $\delta^{15}N$ values for the camelids. The $\delta^{15}N$ values were especially high. The llamas analysed by Díaz-Bonilla et al. (2016) for Playa Miller 7 in Arica, also indicate high $\delta^{15}N$ values for a terrestrial herbivore, with some individuals reaching up to 11‰.

4.2 Materials and Methods

4.2.1 Materials

For this thesis, modern plant samples were collected for carbon and nitrogen isotope analysis in different locations of northern Chile (Figure 4.1). A total of 50 modern samples (Appendix 4.1) were collected, including 44 C_3 plants (*Festuca chrysophylla*, *Senecio eriophyton*, *Acantholippia deserticola*, *Geoffrea decorticans*, *Schinus molle*, *Prosopis tamarugo*, *Prosopis algarrobo*) and 6 C_4 plants (*Atriplex sp.*). Species identification was made for 40 of these samples. The other 10 samples were classified as indeterminate. Most of the samples come from the *Pampa del Tamarugal*, the Atacama Oases and its highlands. The samples were obtained from different altitudes, ranging from 990 masl- 4500 masl in different locations of the Tarapacá and Atacama cultural areas. Samples were collected in paper bags. Due to the arid conditions of the Atacama Desert, the samples were easily and quickly dried.

Modern animal samples consisted of three pelican bone samples from the coast of Los Verdes, close to the Iquique city, collected directly from dead birds cast ashore on the beach.

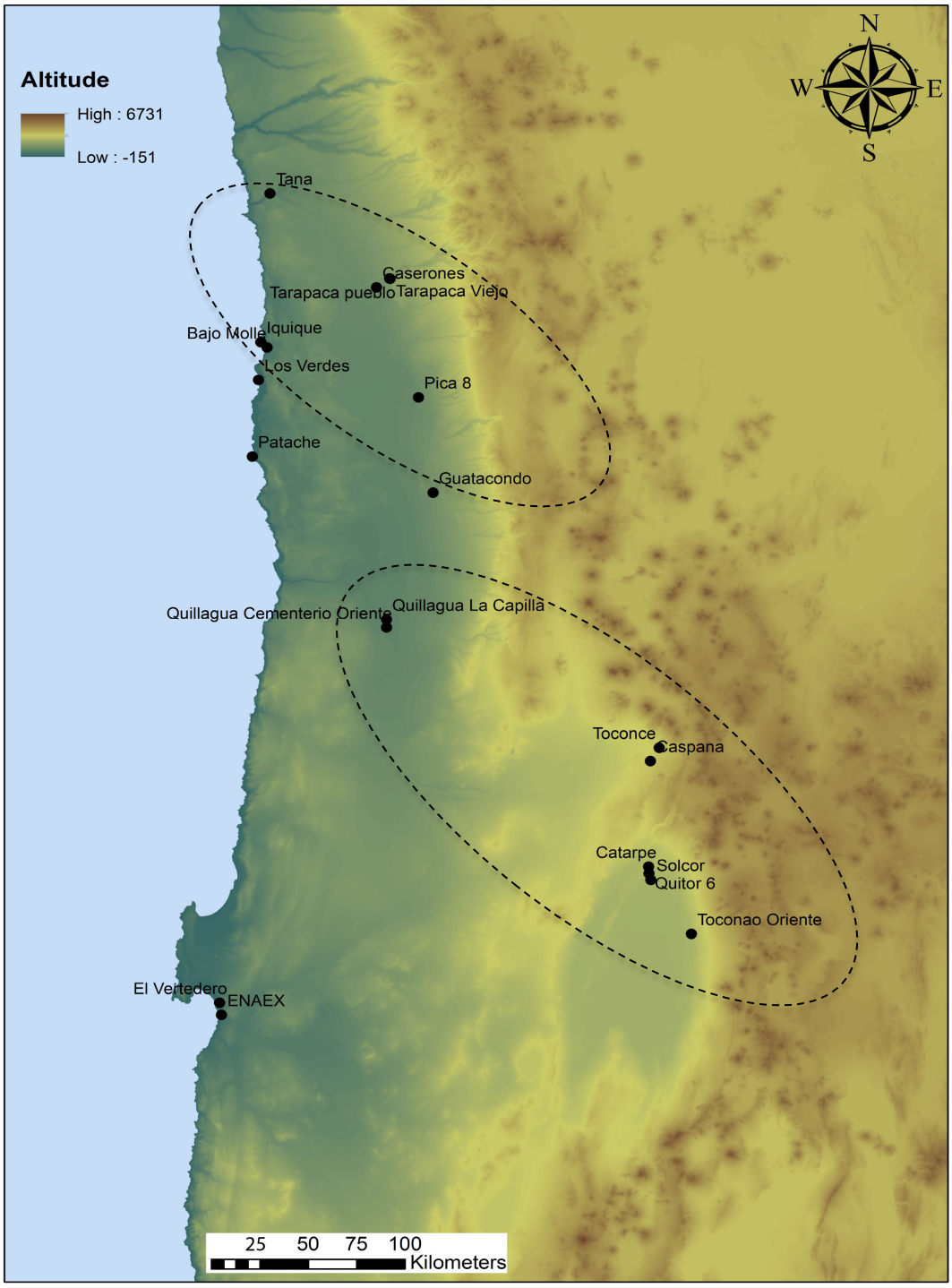


Figure 4.1. Map of northern Chile. Areas from where modern plant samples were taken are indicated by dot ellipses. Archaeological plant and animal samples come from the different archaeological sites indicated by black dots.

A total of 68 archaeological plant samples were included in the analysis. These samples derive from archaeological excavations and rescue efforts in the Tarapacá and Atacama cultural areas (Figure 4.1). More specifically, samples were obtained

from the Museo Regional de Iquique (Iquique), Museo de Antofagasta (Antofagasta), Instituto de Investigaciones y Museo RP Gustavo Le Paige (San Pedro de Atacama), and the archaeological collections of the Departamento de Antropología of the Universidad de Chile (Santiago). Although the LIP was targeted for sampling, the paucity of suitable material associated with this period required the sampling of plant material from the Formative, Middle and Late Periods. Information about the archaeological sites and period of the plant samples collected is presented in Appendix 4.1. All the species were identified including archaeological crops and fruits: *Zea mays*, *Amaranthus* sp., *Lagenaria* sp., *Chenopodium quinoa*, *Capsicum chinense*, and *Prosopis algarrobo*, respectively.

Archaeological fauna samples (n=47) were collected from the institutions mentioned above. Llamas, dogs, rodents, fish, marine birds and seals bones were included in the sampling. Unfortunately, it was not possible to identify the fish species. However, it was possible to differentiate between large and small fish, judging for the size of their vertebra bones and otoliths. Large fish will sometimes be more enriched in ^{15}N, due to they higher position in the trophic chain (Tieszen and Chapman, 1992). As with the archaeological plants, animal samples from the LIP were not abundant, and therefore bones from different periods were included in the analysis.

4.2.2 Methods

Modern and archaeological plant samples were ground using a coffee grinder, and homogenised. Samples were washed and centrifuged three times with Milli-Q water in order to remove any possible nitrate contaminants, following the protocol of Vaiglova et al. (2014). Archaeological plant remains were remarkably well preserved. The Atacama Desert is the driest desert in the world (Clarke, 2006); and as such, there are very few water sources that could have become in contact with the samples. Therefore, no pre-

treatment was performed for removing humic acids. Plants were left in the freeze drier overnight before mass spectrometric analysis.

Samples were weighed into tin cups, and analysed in duplicate in separated runs for carbon and nitrogen isotopes. The analyses were carried out in a SERCON 20/22 continuous flow mass spectrometer coupled with an elemental analyser. Results were calibrated and checked for precision using the international IAEA-C6 and Caffeine #1 standards, and an internal Alanine standard, for carbon isotopes; and USGS-40, USGS-41 and Alanine for nitrogen isotopes. The analytical precision obtained for $\delta^{13}C_{VPDB}$ isotopes was of 0.1‰ and 0.3‰ for $\delta^{15}N_{AIR}$.

Modern and archaeological bone animal samples were pre-treated following a modified version of the Longin (1971) method. Approximately 1 gram of bone was used for collagen extraction. Samples were allowed to stand in 0.5M HCl for 5 days, changing the acid solution every other day. The resulting collagen was gelatinised by heating for 48 hours at 72ºC. Samples were filtered using Eeze filters and later freeze-drier for 48 hours. Collagen was weighed (1.00-1.10 mg) and analysed in duplicate. Analyses were performed in the same mass spectrometer used to analyse the plants samples. The data obtained from the analyses was then calibrated using the in-house standards alanine, seal, cow, and the international standard C6. The analytical precision obtained for carbon isotopes was of 0.1‰ and 0.2‰ for nitrogen.

After the industrial revolution and during modern times, the concentration of CO_2 coming from fossil fuels (enriched in ^{12}C) has increased in the atmosphere. As a consequence of this modern plants and terrestrial animals tend to show lower $\delta^{13}C$ values. This is known as the Suess effect (Suess, 1955). For this reason, when comparing modern carbon plant values with those of archaeological plants, a correction of 1.8‰ was applied to the samples collected in 2014. Modern animal

samples were also corrected for the Suess effect, by +1.7‰ for samples dating to 2010 and by +1.8‰ for samples collected in 2014. These corrections were made based on the information available for the Baring Head Station in New Zealand, published by the Carbon Dioxide Information Analysis Center[1].

4.2.3 Statistical Analysis

All the statistical analyses, descriptive and inferential, were done using the R Project: for Statistical Computing (2003). Normality was evaluated using the Shapiro Wilk test. Even though some of the results show normal distribution, non-parametrics tests were used when comparing the results with data not normally distributed.

4.3 Results

4.3.1 *Modern Plants*

Descriptive statistics for modern C_3 and C_4 plants are presented in Table 4.1. Detailed information about each sample can be found in Appendix 4.1. The mean $\delta^{13}C$ is -25.0±1.9‰ for C_3 plants and -14.0±1.0‰ for C_4 plants. Nitrogen isotopes show means of 0.3±4.2‰ and 5.5±2.2‰ for C_3 and C_4 respectively. C_3 plants present wider ranges of values for their carbon and nitrogen compositions compared to C_4 plants. The difference between the maximum and minimum carbon isotope values for C_3 plants is 7.5‰, while this variation for C_4 plants is 2.4‰. C_3 plants are also more variable in their $\delta^{15}N$ values, ranging from -9.5‰ to 7.9‰. Nitrogen isotope values below 0‰(AIR) were only found in C_3 plants. While lower on average, C_3 plants show the highest $\delta^{15}N$ value with a maximum of 7.9‰ compared to a maximum of 7.7‰ for C_4 plants.

[1] Carbon Dioxide Information Analysis Center website: cdiac.ornl.gov

Considering that these modern samples were collected from different altitudinal gradients, the correlation between their isotope values and elevation was evaluated. For C_3 plants the correlation between $\delta^{13}C$ values and altitude was low presenting a R^2 value of 0.173. For the $\delta^{15}N$ values there was no correlation (R^2=0.005). When the C_3 and C_4 plant values were compared together versus altitude no correlation was found (R^2=0.003 for $\delta^{13}C$ and R^2=0.002 for $\delta^{15}N$). The correlation between C_4 plants and altitude was not calculated given the very small dataset for them (n=6).

Detailed descriptive statistics are presented for each modern species in Table 4.1. Carbon and nitrogen values for all the species and indeterminate individuals are plotted in Figure 4.2. The lowest $\delta^{13}C$ values were observed for the species *Schinus molle* (-28.6‰), followed by *Prosopis tamarugo* (-28.4‰) and *Festuca chrysophylla* (-27.2‰). Together with *Festuca chrysophylla*, *Geoffroea decorticans*, *Prosopis algarrobo*, *Prosopis tamarugo* and *Schinus molle* also present means below 0 for $\delta^{15}N$. The species *Acantholippia deserticola* (7.9‰), *Atriplex sp*. (C_4, 7.7‰) and *Senecio eriophyton* (6.9‰) show the highest $\delta^{15}N$ signals. However, the indeterminate species also presented notably high values for its nitrogen isotope composition (7.3‰).

4.3.2 Modern Animals

Three modern pelicans were analysed for carbon and nitrogen isotopes (Table 4.2, Figure 4.4). The means observed for carbon and nitrogen isotopes are -13.0±1.0‰ and 18.2±1.2‰, respectively.

4.3.3 Archaeological Plants

Results for the different types of archaeological plants - including crops, fruits and wild plants, are presented in Table 4.1 and Figure 4.3. Detailed information about each sample can be found in Appendix 4.1.

The results for carbon isotopes show that there is a normal distribution for the C_3 archaeological plants - wild, crops and fruits (W=0.9529; p-value=0.2707), C_3 modern plants (W=0.9845; p-value=0.8091) and C_4 modern plants (W=0.8398; p=0.1298), with the exception of C_4 archaeological plants (W=0.8744; p-value=6.539e-05).

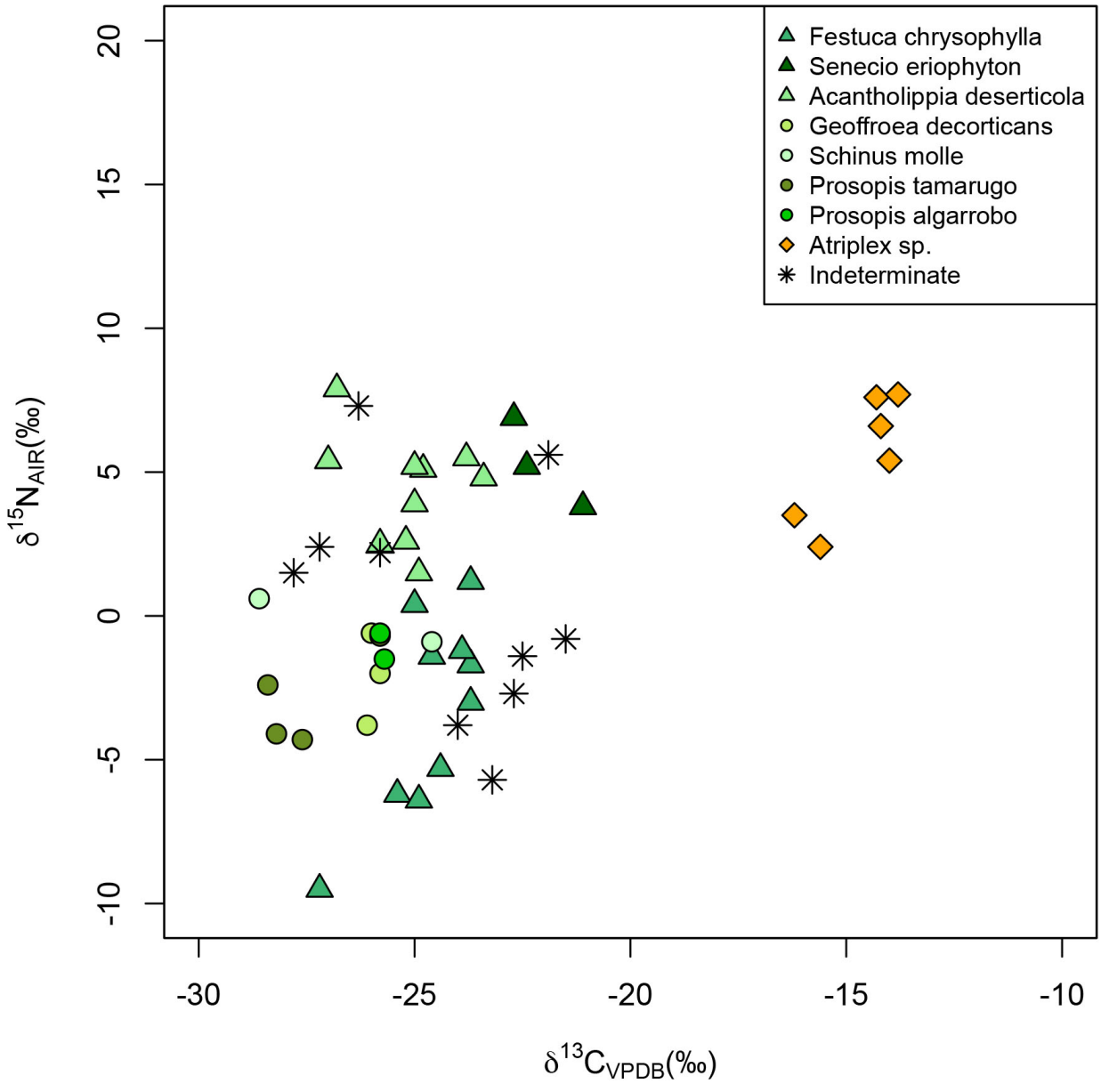


Figure 4.2. Bivariate plot for $\delta^{13}C$ and $\delta^{15}N$ values of modern wild plants from northern Chile.

Normal distributions were also reported for nitrogen isotopes: modern plant samples (W=0.969; p-value=0.228), archaeological crops (W=0.973; p-value=0.234) and

archaeological fruits (W=0.954; p-value=0.548). Wild archaeological plants were not considered for normality evaluation because of its small sample number (n=3).

C_3 crops (*Lagenaria sp*., *Chenopodium quinoa* and *Capsicum chinense*) present a mean of -21.5±1.6‰ and 22.5±6.0‰ for their $\delta^{13}C$ and $\delta^{15}N$ values, respectively. The $\delta^{15}N$ values show high variation ranging from 12.8‰ to 28.5‰. On the other hand, C_4 crops (*Zea mays* and one sample of *Amaranthus sp.*) show a mean of -10.6±0.9‰ and 14.4±8.0‰ for carbon and nitrogen isotopes respectively. As inferred from the standard deviation of $\delta^{15}N$ values, there is extreme variation in the nitrogen isotope values ranging from 1.8‰ to 37.0‰ (Figure 4.3).

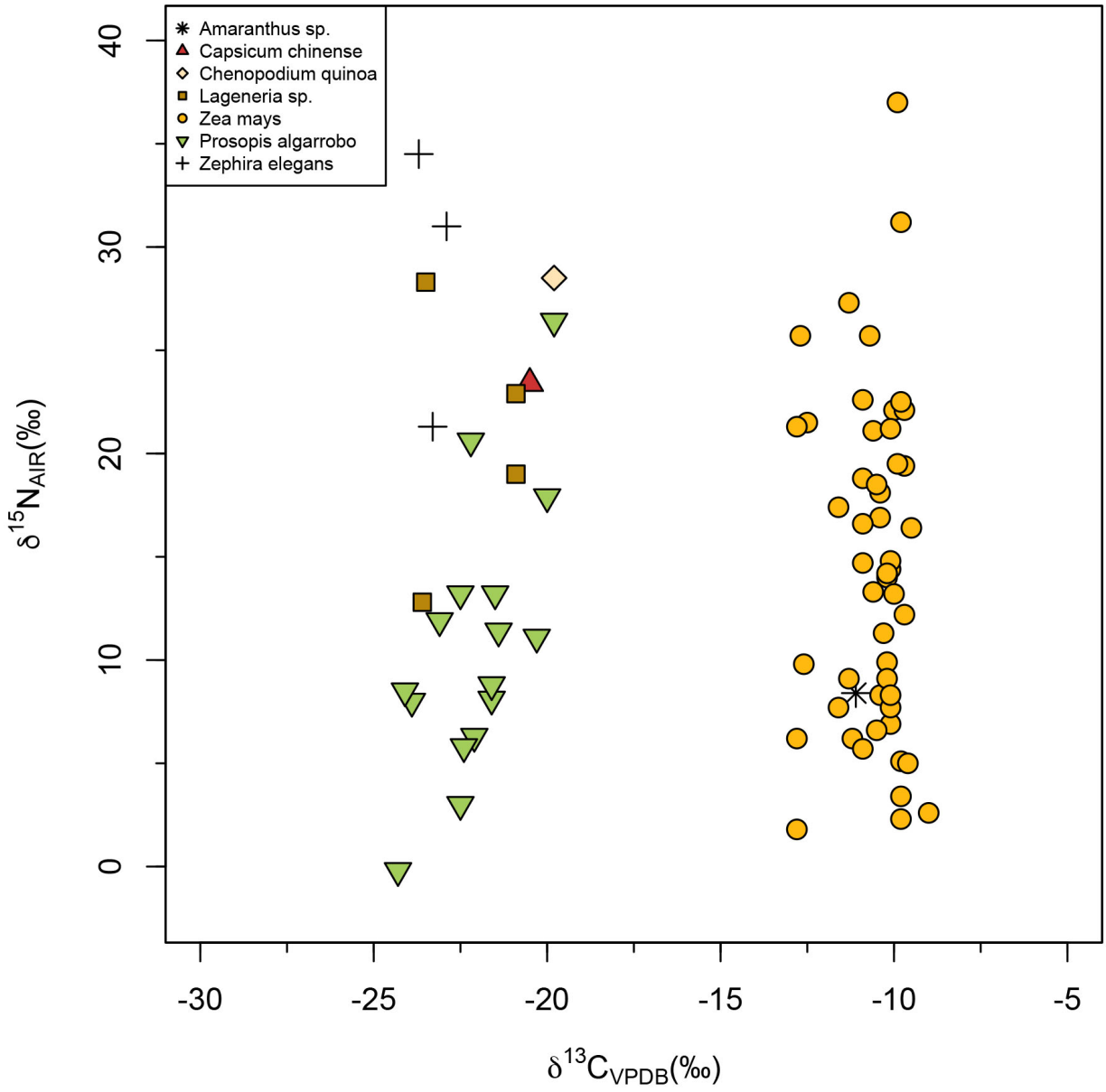


Figure 4.3. Bivariate plot for $\delta^{13}C$ and $\delta^{15}N$ values of archaeological wild plants, fruits and crops from northern Chile.

The mean observed for carbon isotopes is -22.1±1.4‰ and that of nitrogen is 10.9±6.6‰ for the fruit (*Prosopis algarrobo*). A similar situation to the one observed

before for C_4 crops is repeated here, whereby a very high variation is observed in $\delta^{15}N$ values that range from -0.2‰ to 26.4‰. The wild coastal plant, *Zephira elegans*, has a mean of -23.3±0.4‰ for $\delta^{13}C$ and 28.9±6.8‰ for $\delta^{15}N$. Following the same pattern observed for C_4 crops and the fruits, there is also a wide range for nitrogen isotopes values, specifically from +21.3‰ to 34.5‰.

Detailed information on the descriptive statistics for each archaeological species analysed here is presented in Table 4.1.

The lowest and highest value for $\delta^{13}C$ between the C_3 crops, fruits and wild plants comes from the coastal *Zephira elegans* with -23.7‰ and *Chenopodium quinoa* with -19.8‰, respectively. For C_4 crops the minimum and maximum carbon isotope values observed for *Zea mays is* -12.8‰ and -9‰, respectively. Nitrogen isotopes in the C_3 category show minimum and maximum values with -0.2‰ and 34.5‰, for *Prosopis algarrobo* and *Zephira elegans*, respectively. On the other for the C_4 plants, the lowest and highest values were registered for *Zea mays* with 1.8‰ and 37.0‰.

Modern and archaeological plants were compared for their carbon and nitrogen isotope composition. Comparison of modern and archaeological C_3 plants shows significant differences (W=779; p-value=0.012). A similar situation is observed when comparing modern and archaeological C_4 plants (W=300.5; p-value=0.002).

Modern plants were significantly different when compared to archaeological crops (W=2214.5; p-value=6.006e-15) and fruits (W=744; p-value=2.746e-07) for their $\delta^{15}N$ values. Statistically significant differences were also observed between the archaeological crops and fruits (W=495; p-value=0.04). Wild archaeological plants were not compared because of its small sample number (n=3).

Table 4.1. Descriptive statistics for modern and archaeological plants by species, where M=Modern, A=Archaeological, W= Wild, C=Crop and F=Fruit.

Chron.	Type	Species	Mean		SD		Max		Min	
			$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
M	W	*Acantholippia deserticola*	-25.2	4.4	1.1	1.9	-23.4	7.9	-27.0	1.5
M	W	*Atriplex sp.*	-14.7	5.5	1.0	2.2	-13.8	7.7	-16.2	2.4
M	W	*Festuca chrysophylla*	-24.7	-3.3	1.1	3.4	-23.7	1.2	-27.2	-9.5
M	W	*Geoffroea decorticans*	-26.0	-2.1	0.2	1.6	-25.8	-0.6	-26.1	-3.8
M	W	*Prosopis algarrobo*	-25.8	-1.1	0.1	0.6	-25.7	-0.6	-25.8	-1.5
M	W	*Prosopis tamarugo*	-27.5	-2.9	1.2	1.7	-25.8	-0.7	-28.4	-2.4
M	W	*Schinus molle*	-26.6	-0.2	2.8	1.1	-24.6	0.6	-28.6	-0.9
M	W	*Senecio eriophyton*	-22.1	5.3	0.9	1.5	-21.1	6.9	-22.7	3.8
M	W	Indeterm.	-24.3	0.5	2.3	4.1	-21.5	7.3	-27.8	-5.7
A	C	*Amaranthus sp.*	-11.1	8.4	0	0	-11.1	8.4	-11.1	8.4
A	C	*Capsicum chinense*	-20.5	23.4	0	0	-20.5	23.4	-20.5	23.4
A	C	*Chenopodium quinoa*	-19.8	28.5	0	0	-19.8	28.5	-19.8	28.5
A	C	*Lagenaria sp.*	-22.2	20.8	1.5	6.5	-20.9	28.3	-23.6	12.8
A	F	*Prosopis algarrobo*	-22.1	10.9	1.4	6.6	-19.8	26.4	-24.3	-0.2
A	C	*Zea mays*	-10.6	14.5	1.0	8.0	-9	37	-12.8	1.8
A	W	*Zephira elegans*	-23.3	28.9	0.4	6.8	-22.9	34.5	-23.7	21.3

4.3.4 Archaeological Animals

Out of the total of 47 faunal samples, 10 were excluded from further analysis due to insufficient collagen preservation, with C/N ratios higher than 3.6. Information about the carbon and nitrogen composition of each sample together with collagen yield, %C, %N and C/N ratios can be found in Appendix 4.2. Results presenting descriptive statistics for the different animal types are shown in Table 4.2.

The marine fauna shows the highest values for $\delta^{13}C$ and $\delta^{15}N$ (Figure 4.4). Seals average -12.2±0.1‰ for carbon isotopes and 20.1±0.8‰ for nitrogen isotopes. Fish show a mean of -12.9±1.2‰ for $\delta^{13}C$, and an average for nitrogen isotopes of 20.2±2.3‰. Marine birds show a more enriched in ^{13}C mean of -12.0±1.1‰ in relation to seals and fish, but a lower mean for $\delta^{15}N$ of 16.3±0.8‰.

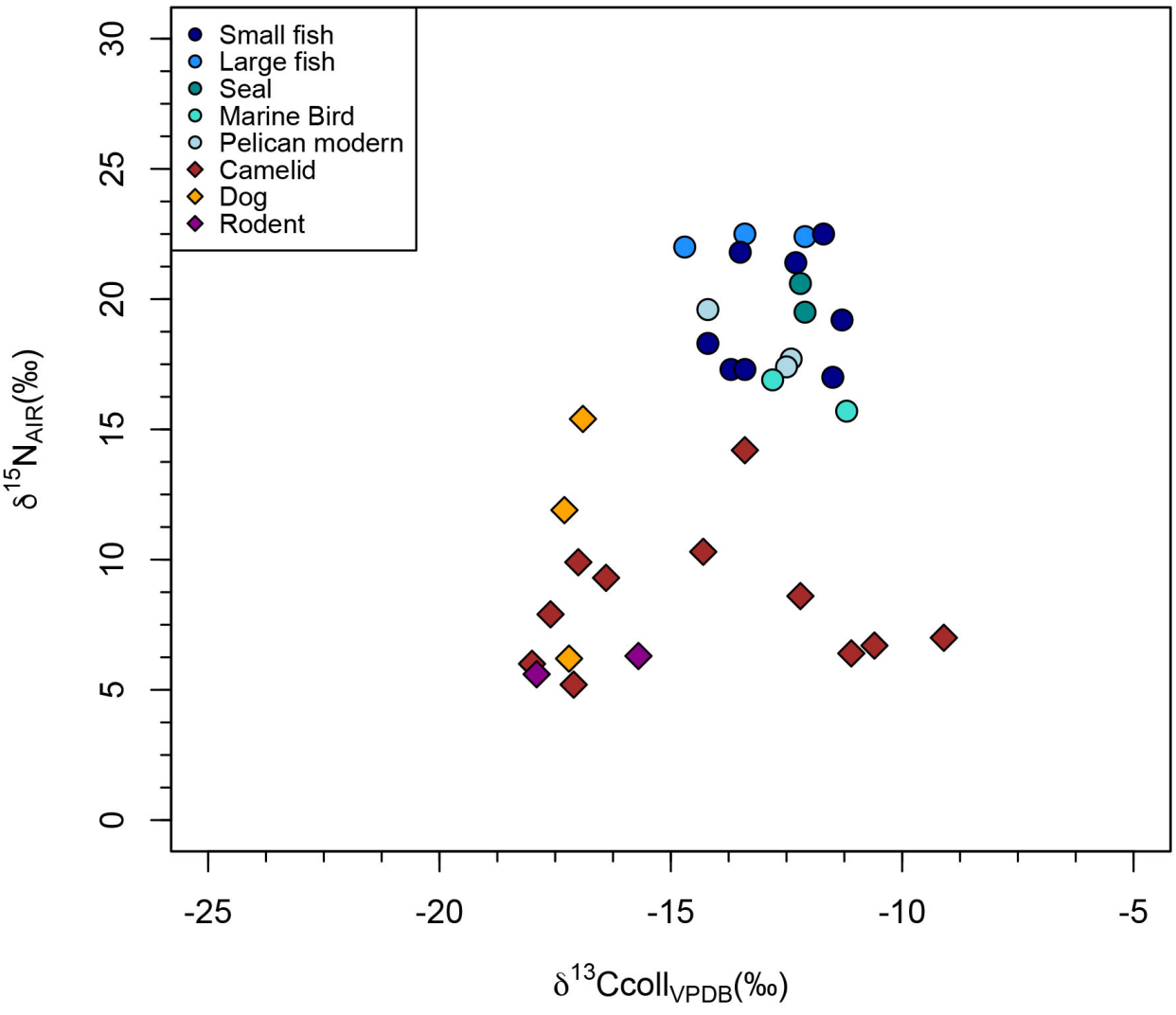


Figure 4.4. Bivariate plot for $\delta^{13}C$ and $\delta^{15}N$ values of archaeological and modern fauna from northern Chile.

Chron.	Animal	Type	Mean		SD		Max		Min	
			$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Arch.	Seal	Marine	-12.2	20.1	0.1	0.8	-12.1	20.6	-12.2	19.5
Arch.	Fish	Marine	-12.9	20.2	1.2	2.3	-11.3	22.5	-14.7	17.0
Arch.	Bird	Marine	-12.0	16.3	1.1	0.8	-11.2	16.9	-12.8	15.7
Modern	Pelican	Marine	-13.0	18.2	1.0	1.2	-12.4	19.6	-14.2	17.4
Arch.	Dog	Terrest.	-17.1	11.2	0.2	4.6	-16.9	15.4	-17.3	6.2
Arch.	Camelid	Terrest.	-14.3	8.3	3.2	2.6	-9.1	14.2	-18.0	5.2
Arch.	Rodent	Terrest.	-16.8	6.0	1.6	0.5	-15.7	6.3	-17.9	5.6

Table 4.2. Descriptive statistics for archaeological and modern animals

Terrestrial animals show both lower carbon and nitrogen values. Camelids (*Llama glama*) present a mean of -14.3±3.2‰ for $\delta^{13}C$ and 8.3±2.6‰ for $\delta^{15}N$. Dogs show a more depleted in ^{13}C mean compared to camelids, averaging -17.1±0.2‰, but a higher $\delta^{15}N$ mean of 11.2±4.6‰. At the same time, dogs registered the minimum $\delta^{13}C$ and maximum $\delta^{15}N$ values observed for all terrestrial animals, with -16.9‰ and 15.4‰, respectively. Rodents present a mean of -16.8±1.6‰ for carbon and the lowest $\delta^{15}N$ mean for all the animals analysed here with 6.0±0.5‰.

4.4 Modern and archaeological plant isotope composition in the Atacama Desert

4.4.1 Modern Plants isotope composition in the Atacama Desert

As would be expected, modern C_3 and C_4 plants are clearly separated in terms of their carbon isotope composition (Figure 4.2). However, there is considerable variability within the C_3 plants, ranging from -28.6‰ to -21.1‰. Previous research in Peru (Szpak et al., 2014) and northern Chile (Tieszen and Chapman 1992) suggest that carbon isotope values show a positive correlation with the altitudinal gradient and mean annual precipitation. However, this correlation was not observed for the plants collected in this study as reflected in the low correlation (R^2 = 0.172) between the $\delta^{13}C$ values of C_3 plants and altitude. In any case, the number of samples included in this thesis is

considerable lower than that analysed by Tieszen and Chapman (1992), a factor that may be affecting the results.

Even though the lowest values for $\delta^{13}C$ come from the species *Prosopis algarrobo* and *Schinus molle* growing at lower elevations between 1000-2500 masl, other species growing above 3000 masl are either/both enriched and depleted in ^{13}C. For instance, the species *Senecio eriophyton* - growing between 3000-3700 masl, have the highest values for carbon isotopes. However, *Acantholippia deserticola* growing at the same altitudes presents somewhat negative $\delta^{13}C$ values (around -27‰). Similarly, Samec et al. (2015) did not find a correlation between carbon isotopes and altitude for northwest Argentina. This area is fairly close to the Atacama Oases and its highlands are similar to the latter region in terms of geography and ecological characteristics. The authors were unable to explain the reasons behind this lack of correlation in the *Puna Salada* area. It is necessary to evaluate if these correlations or lack of correlations are species-specific in future research, analysing a bigger set of samples from Chile and Argentina.

An extremely high variation is observed in the nitrogen isotope composition of both C_3 and C_4 plants. Lowest values are observed for the non-fixer species *Festuca chrysophylla*. This species grows at very high altitudes between 3700-4500 masl, being fully adapted to the cold conditions of the area. Other specimens, of indeterminate species, from altitudes above 3700 masl also show low $\delta^{15}N$ values. The C_3 species *Acantholippia deserticola*, *Senecio eriophyton* (both growing between 3000-3700 masl) and the C_4 species *Atriplex sp*. (1000-3700 masl) show relatively higher $\delta^{15}N$ values, between 6‰-7.9‰. As with the case of carbon isotopes, no statistically significant correlation was detected between $\delta^{15}N$ and altitude (R^2=0.004) for this study.

Contrary to these results, Díaz et al. (2016) suggest that there is a negative correlation between the $\delta^{15}N$ values and altitude for the Atacama Basin and its highlands. Their work shows that most of the plants growing at higher altitudes (above 3000 masl) tend

to show lower nitrogen isotopes. Nevertheless, it is possible that the sample size and the type of species collected here (different to those analysed by Díaz et al., 2016) could be affecting the results, as mentioned above. The lack of correlation observed could also be affected by the presence at lower altitudes (1000-2500 masl) of N^2-fixer species such as *Prosopis algarrobo*, *Prosopis tamarugo* and *Geoffrea decorticans*, all of them showing, as expected, very low values for $\delta^{15}N$.

As suggested in previous local studies by Evans and Ehleringer (1994) and Díaz et al. (2016), the nitrogen isotopic composition of plants is clearly influenced by the extremely arid conditions of the Atacama Desert. The main factors leading to higher $\delta^{15}N$ values in plants are the combined effects of aridity and high temperatures on soils, and the presence of nitrate deposits (Heaton, 1987; Evans and Ehleringer, 1994; Díaz et al., 2016). The hyper-arid conditions and elevated temperatures lead to high volatilization of inorganic N in the soils that leads in turn to ^{15}N-enrichment (Heaton, 1987; Evans and Ehleringer, 1994; Díaz et al., 2016). Therefore, it is not surprising to find plants with relatively enriched in ^{15}N in the study area. Evans and Ehleringer (1994) reported values up to 11‰ (n = 24) for plants in the coast of Paposo, while Díaz et al. (2016) registered lower maximum values of around 8.8‰ (n = 66).

The results obtained in this thesis were compared with the carbon and nitrogen isotope observations obtained by Díaz et al. (2016) for modern foliar plants and modern rodent faeces collected from rodent middens sampled along the Talabre-Lejía transect, close to the Atacama Oases. As shown in Figure 4.5 the values for the C_4 modern plants obtained here are similar to those obtained by Díaz et al. (2016). Rather, the main differences observed between the results of Díaz et al. and this study are observed for $\delta^{15}N$ values of C_3 plants. These differences are statistically significant (W=2342; p-value= 3.588e-06). As noted above, this difference may be due to the larger numbers

of *Festuca chrysophylla,* which have low $\delta^{15}N$ values, and which were not sampled by Díaz et al. (2016). Modern faeces from rodent middens of the same transect show a clear relation to the $\delta^{15}N$ values of modern foliar plants obtained by Díaz et al, and this study (when ommitting *Festuca chrysophylla*). They clearly suggest a mixed diet of C_3-C_4 plants for some of the rodents as shown in Figure 4.5. Faeces sometimes preserve entire seeds or other plant parts, thus providing excellent proxies for studying past local flora in the study area (Díaz et al., 2016). Their nitrogen values show very similar numbers to those obtained from modern plants, suggesting that non-digested plant segments were probably directly excreted in some cases, thus revealing the isotopic composition of the plants on which rodents fed.

The high $\delta^{15}N$ values in modern plants reported here need to be considered carefully since they will have a considerable impact on the herbivore's isotopic profiles. The three modern pelican bones are discussed together with the archaeological fauna.

4.4.2 Archaeological Plants: the impact of seabird guano on crops and fruits

As expected the $\delta^{13}C$ values for archaeological plants clearly distinguish C_3 and C_4 taxa. The most striking observation about the archaeological plants is that they are generally extremely ^{15}N-enriched. Remarkably, many of the values observed for crops and fruits are above 20‰, even reaching a maximum of 37‰. These values are unexpected for local crops and fruits, reflecting as they do higher $\delta^{15}N$ values than all the marine animals analysed in this study. Additionally, archaeological plants show markedly higher $\delta^{15}N$ values when compared to their modern counterparts.

There are three possible explanations for these exceptionally high values. They are: 1) the impact of the region's extreme aridity and high temperatures on the plant nitrogen

composition of soils and plants, 2) possible diagenetic processes, and 3) the systematic use of highly ^{15}N-enriched fertilisers during pre-Columbian times.

The first explanation may easily be discarded. As discussed in the previous section, modern plants that are affected directly by aridity reach only maximum values around 11‰ (Evans and Ehleringer, 1994; Díaz et al., 2016). Additionally, the soil δ^{15}N profiles for the Atacama Desert do not include values higher than 11‰ (Díaz et al., 2016). Furthermore, ancient rodent faeces – that consist largely of plant remains - dating to 2000-500 years ago from the Atacama region show maximum values of 16‰ (Díaz 2014) (Figure 4.5).

This evidence suggests that, while the wild flora between 2000-500 years ago had higher δ^{15}N compared to more temperate, less arid environments, they did not reach the values seen for archaeological crops and fruits in the present study. Consequently, the aridity of the area cannot explain the extremely ^{15}N-enriched archaeological plant values.

The second explanation invokes chemical alteration (diagenesis) of the plants. Hastorf and DeNiro (1985) observed markedly high δ^{15}N values in non-charred archaeological plants from different coastal and inland sites in northern and central Peru. Some plants were as high as +36‰. These values did not change even when different pre-treatments were performed in order to remove any possible contaminants (considered to possibly be humic acids). They discounted the action of bacterial origin on the material. DeNiro and Hastorf (1985) were unable to account for the observed ^{15}N enrichment in non-charred plants, and as a result, deduced that the only remaining explanation (to them) was related to diagenesis.

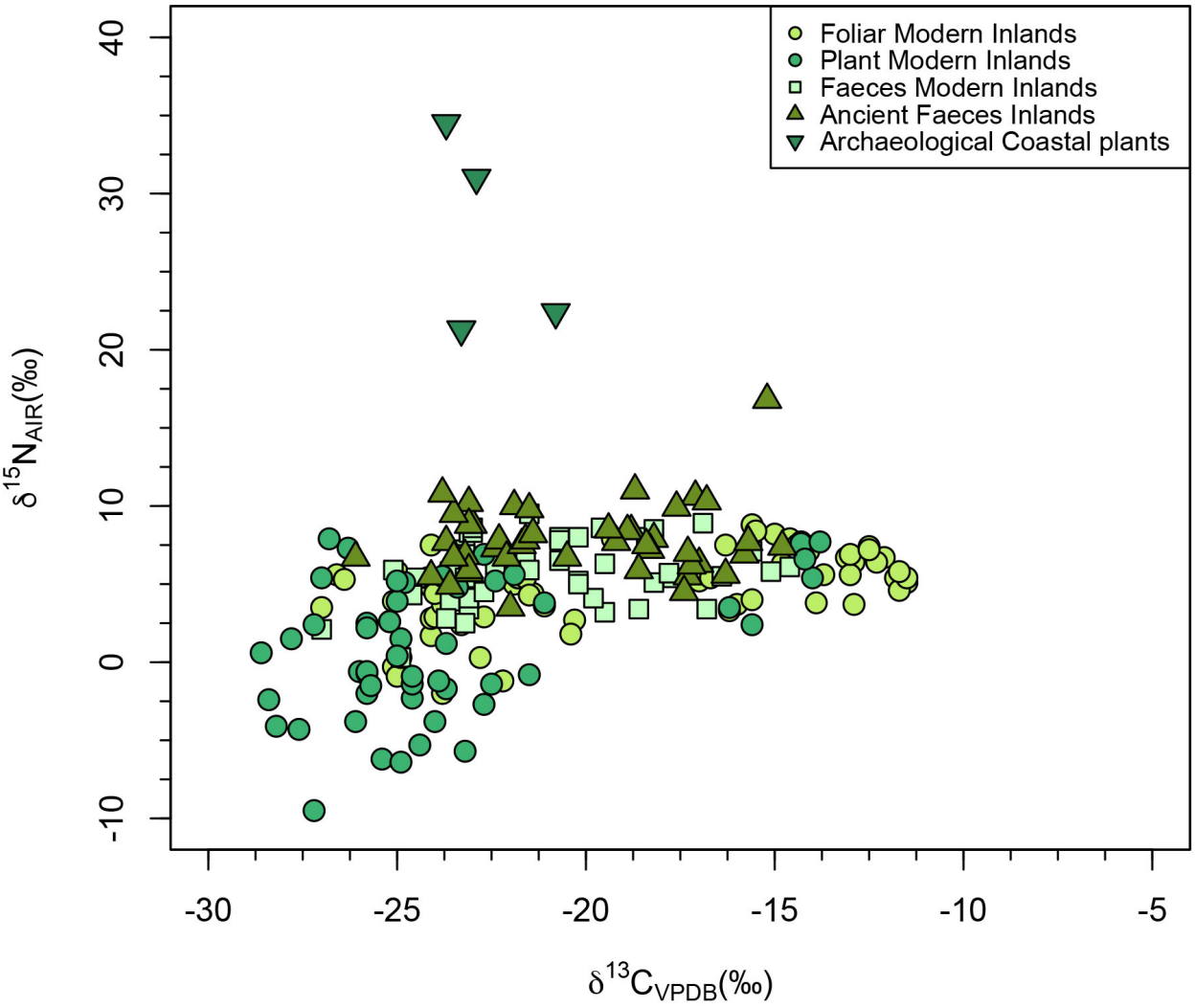


Figure 4.5. Bivariate plot for $\delta^{13}C$ and $\delta^{15}N$ values of modern and wild archaeological coastal plants obtained in this study together with modern foliar values, ancient and modern rodent faeces obtained by Díaz (2014) and Díaz et al. (2006) from northern Chile.

Both that Peruvian study and the present work deal with similar environments, which are characterised by very arid conditions. For this reason, the materials in both regions preserve exceptionally well. In the Chilean Atacama Desert, rivers, oases and other sources of water and moisture are very limited. Hence, the possibility that humic acids could have affected the isotopic composition of archaeological plant samples is very unlikely. If any, the main source of contamination could be coming from the soil nitrates

of the desert. However, as previously discussed, the soils and their nitrogen isotopic compositions would not reach values beyond 11‰, and in fact, nitrates from the Atacama Desert show values between -5.0‰ to 5.0‰ (Böhlke et al., 2007). In the present study, plant samples were washed and centrifuged three times with milli-Q water in order to remove any possible contaminating nitrates, as mentioned in the materials and method section. Thus, the diagenesis explanation can also be discarded.

The last hypothesis proposes that the use of fertilisers on crops in the past is the main cause behind the extremely enriched ^{15}N composition in archaeological crops and fruits. Modern experiments on maize plants carried out in Peru, using different fertilisers, such as modern industrial fertilizers, llama dung and seabird guano demonstrate the impact they have on the crop's nitrogen isotope composition (Szpak et al., 2012a, b). Seabird guano (from the Pacific coast) has by far the most substantial effect. After application, $\delta^{15}N$ values reached maximum values of up to 40‰, ranging from 12‰-40‰ for modern maize plants (Szpak et al., 2012 a, b). Llama dung is also effective in enriching ^{15}N, but only up to ca. 12‰.

The archaeological samples analysed here are almost all crops, including maize, squash, quinoa, chilli and amaranthus, which show exceptionally high $\delta^{15}N$ values. Given these very high values, and the outcomes of the Szpak experiments, this result is most likely related to the use of seabird guano as fertiliser when crop fields were tended. The actual use of seabird guano by the Inkas and local communities has been recorded in many European chronicles during the XVI-XVIII centuries (Julien, 1985). In fact, ethnohistorical records mention that without the use of seabird guano, maize harvests would have been much reduced in the coastal valleys of northern Peru and northern Chile (Arica) (Julien, 1985). Therefore, this natural manure was essential for a successful management of agricultural activities during Inka times. Given its pivotal role in Inka agricultural productivity, it is not surprising that there was a complex guano

trade system connecting the coast with inland areas (Frezier, 1717). It is very likely that this well documented practices extended further into the past including the LIP. The great abundance of maize evidence and other crops in LIP sites located in the arid endorheic areas of the Atacama Desert could support this hypothesis.

It is worth noting that the hypothesised use of seabird guano is strengthened by a clear temporal pattern in its use on crops. As outlined in the methodology, the samples analysed here belong to different archaeological periods from the Formative (transition to agriculture) until Inka times. Figure 4.6 shows an increment in $\delta^{15}N$ values of crops *after* the transition to agriculture. These results are consistent when one considers that agricultural activities only became fully developed rather late in northern Chile, between the Middle Period and Inca times (Uribe, 2006) and not before (e.g. Formative Period – Santana-Sagredo et al., 2015c).

Some samples of the fruit *Prosopis algarrobo* are also ^{15}N-enriched. However, this need not be surprising. it has been proposed that this tree species was introduced in northern Chile (McRostie 2014) probably immediately before the beginning of the Formative Period (1000 BC - 400 AD). Hence, the fruits were most probably cultivated. In fact, plenty of evidence from the inland Formative-Late Intermediate Period site of Caserones strongly suggests that *Prosopis algarrobo* forests were managed and irrigated (Núñez, 1986; Núñez and Holder, 1993).

The ^{15}N-enrichment might then be related to the spaces where these trees were growing, near agricultural fields, which would be concentrated wherever there was sufficient water (i.e., the oases). By standing adjacent to the agricultural fields and their irrigation systems, they probably benefitted from the use of fertilisers at these locations.

Even though *Prosopis algarrobo* is an N^2-fixer species and its $\delta^{15}N$ values are expected to be quite low (as shown for the modern cases), only a few of the archaeological samples presented figures below 0‰. Moreover, those samples with low $\delta^{15}N$ (t<0‰) values date to the Formative Period, when agriculture was still being developed, and probably no seabird guano was used.

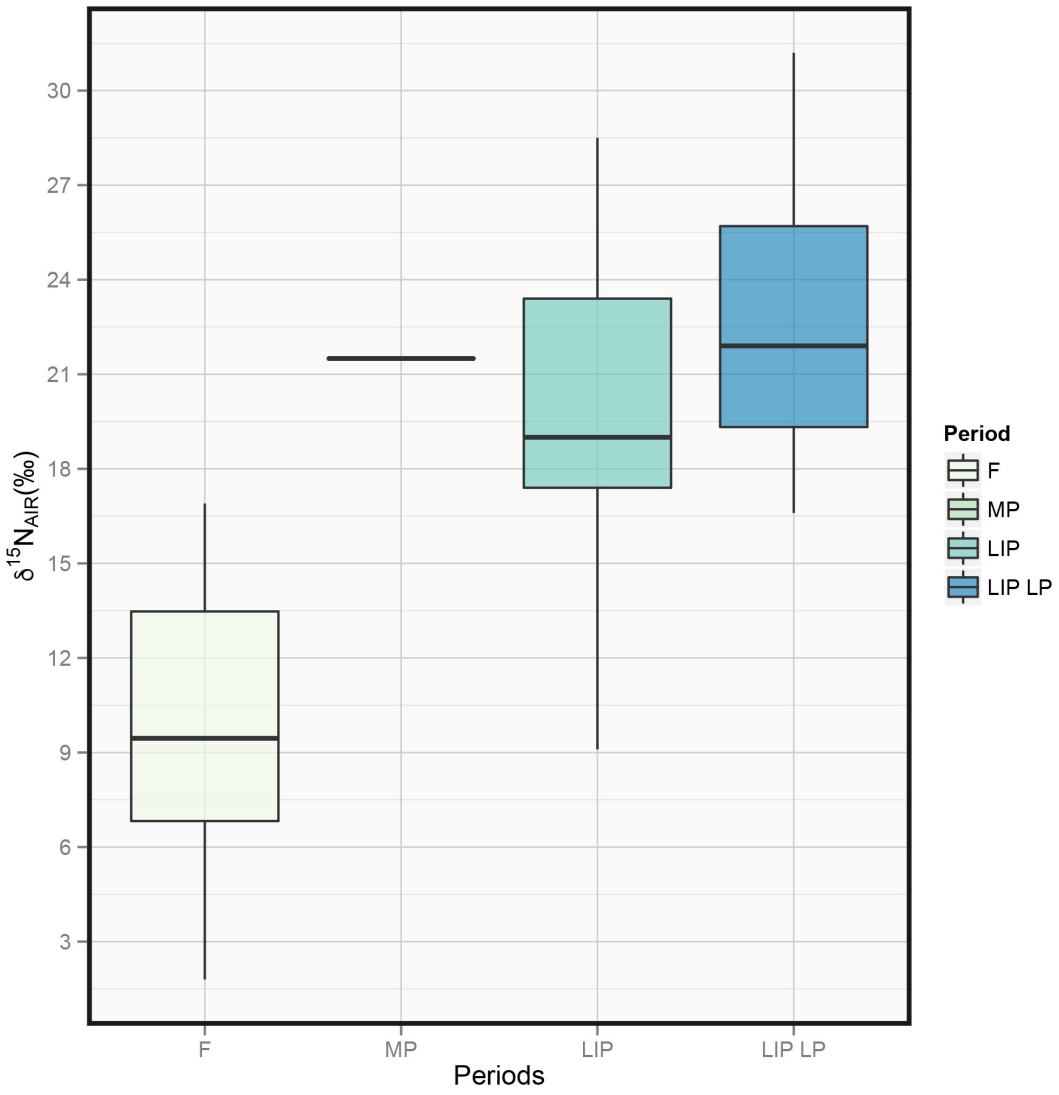


Figure 4.6. Boxplot showing $\delta^{15}N$ values through the Formative, Middle, Late Intermediate and Late Period in northern Chile.

Modern experimental studies carried out in legumes show that fertilisers can heavily influence even the nitrogen isotopic composition of N^2-fixers (Szpak et al., 2014).

Three archaeological wild plants were also analysed here, belonging to the coastal species *Zephira elegans*. This is a wild C_3 plant that grows in the arid coastal environment thanks to the influence of the fogs formed by the marine system. Assuming that seabird guano would be used as a fertiliser only on the crops (and *Prosopis algarrobo* by default, as explained before), it is not expected to observe an enrichment of ^{15}N in the isotopic composition of these particular wild plants. However, they show remarkably high $\delta^{15}N$ values. The most plausible explanation for this enrichment is that the seabird guano that naturally accumulated at and near the coast affected the isotopic composition of these wild plants. These plants grow nowadays next to where guano factories were based during the XIX century. Seabird guano accumulations are massive along the coast of northern Chile (Méndez-Quiros and Aravena, 2012). The few plants that grow in this region are closely distributed along this coastline due to the limited availability of fog moisture and local coastal topography that is shaped by the steeply abrupt Coastal Cordillera situated almost immediately to the east of the coast.

As discussed previously, wild plants from inland locations do not show such high $\delta^{15}N$ values if we consider the ancient faeces analysed by Díaz (2014) as a proxy. The maximum values observed only reach 16‰. For this reason, the hypothesis that posits a direct influence of seabird guano on the nitrogen composition of wild plants growing at the coast is here supported.

4.5 Modern and Archaeological Animal isotope composition in the Atacama Desert

The stable isotope analysis for the local fauna shows a clear separation between the marine and terrestrial animals. Marine fauna shows, as expected, high $\delta^{13}C$ and $\delta^{15}N$

values. The results are in agreement with the previous research done on modern fauna by Tieszen and Chapman (1992). They discussed the absence of the typical trophic chain pattern expected for ocean ecosystems, in which seals at the top of the food chain on average present the highest $\delta^{15}N$ values. Here, the archaeological results show the same trend as in the modern cases. Even though the sample size is in this study small, the pattern is evident, confirming to the patterns observed by Tieszen and Chapman (1992). For instance, the maximum values for fish and seals obtained by these authors are 22.4‰ and 21.2‰ respectively, being very similar to the ones reported here with 22.5‰ for fish and 20.1‰ for the seals. In addition, these values are notably high compared to other marine environments such as Central Chile, in which usually the maximum values observed are around 18-20‰ for seals, and fish are usually no higher than 15‰ (Falabella et al., 2007). All the fauna analysed here, including the archaeological and three modern pelicans, show $\delta^{15}N$ values above 15‰. Tieszen and Chapman (1992) have suggested that this situation might " …occur as a consequence, again, of an upwelling system (see Rau et al., 1989) with numerous trophic tranfers, since an enrichment of 2‰ to 3‰ is clearly documented (Fry, 1991) for each trophic transfer. Our inability to document trophic level differences in this system may simply reflect the complex nature of the trophic transfer of substantial variation in a seemingly small sample area…" (p. 413). Results obtained in this thesis suggest that the complexity inherent in upwelling systems not only affects modern fauna currently but that this was also the case in the past. The noticeably high nitrogen isotope values of the marine fauna would have then contributed to enrich the ^{15}N isotopic composition of its potential human consumers.

In terms of the terrestrial fauna, carbon isotope results suggest that rodents and dogs were probably consuming mainly C_3 diets with some C_4 input. Regarding their nitrogen isotopes, rodents show the lowest values, indicating a different vegetation type ingested compared to camelids.

Dogs, on the other hand, present the highest $\delta^{15}N$ values among the non-human animals, with two showing $\delta^{15}N$ values above 10‰, which is to be expected for an omnivores species. The two individuals with values above 10‰ came from a coastal site close to Iquique and from the Inca site of Tarapacá Viejo, 70 km away from the coast. However, there is one individual showing a value of ca. 6‰. This individual was also sampled from the site Tarapacá Viejo, and even though this and the other specimen show differences in terms of the nitrogen isotope values, their carbon values are actually very similar around -16‰ to -17‰. Their carbon values do not suggest significant consumption of marine resources, and nor this is the case for the specimens showing higher $\delta^{15}N$ values. It is possible that they consumed marine fauna with low $\delta^{13}C$ values but with a more variable nitrogen isotopic composition. In this study, no fauna with such characteristics was observed. However, camelids from high altitudes in northwest Argentina fit with these isotopic profiles (Figure 4.7).

The camelid results for carbon isotopes show a high variability in the values ranging from -18‰ to -9‰. This variation could be suggesting different grazing areas for the camelids analysed here. It has been observed that camelids pasturing at higher elevations show more negative values for $\delta^{13}C$. Camelids living between 3000-4000 masl in northwest Argentina show lower $\delta^{13}C$ values compared to the camelids analysed in this work (Figure 4.8). In fact, when comparing the carbon isotope values for the northwestern Argentinian (Fernández and Panarello 1999-2001; Yacobaccio et al., 2009; Yacobaccio et al., 2010; Samec et al., 2013; Samec, 2014) and Chilean camelids, significant differences can be observed (W=595.9; p-value=1.304e-07).

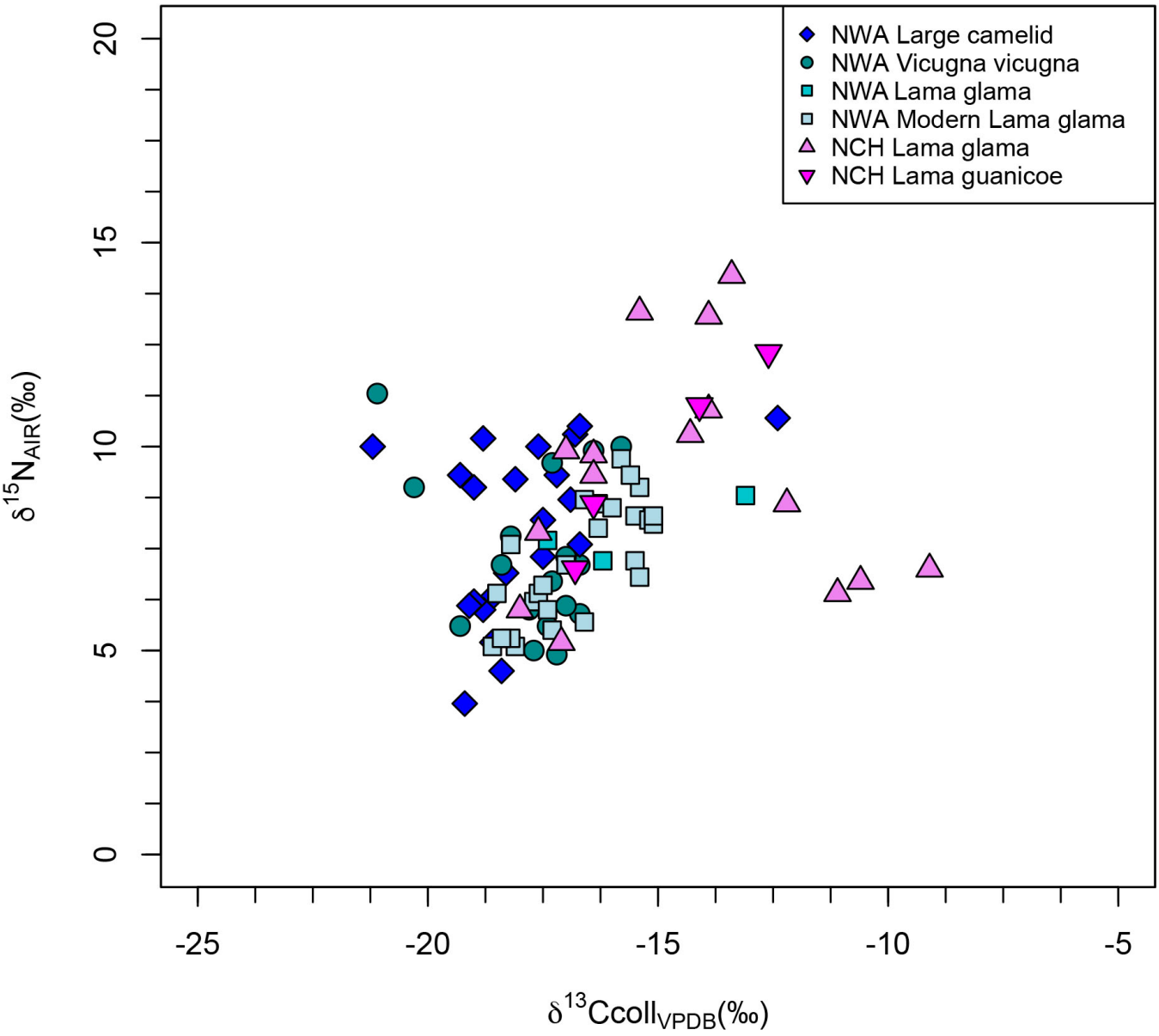


Figure 4.7. Bivariate plot for $\delta^{13}C$ and $\delta^{15}N$ values of archaeological and modern camelids from northernestern Argentina (NWA) and northern Chile (NCH). NWA data was taken from Yacobaccio et al.(2010), Samec et al. (2013) and Samec.(2014). Northern Chile data was obtained in this study and taken from López et al. (2013).

It must be noted that the Chilean camelids from this work and from that of López et al. (2013) were sampled from sites between 1000-2500 masl. Altitude is thus clearly playing a role in the carbon values of the camelids, as suggested by Fernández and Panarello (199-2001), Yacobaccio et al., (2009) and Samec (2014). Comparisons between carbon isotope values for Chilean and northwestern Argentinian camelids established for every 1000 masl show significant differences between the highest and lowest altitudes (1000- 4000 masl; 2000-3000 masl; 2000-4000 masl; 3000-4000 masl; $p<0.05$) (Figure 4.9).

Research done in northwest Argentina (Fernández and Panarello 1999-2001; Yacobaccio et al., 2009; Yacobaccio et al., 2010; Samec et al., 2013; Samec, 2014) strongly suggests that there is an important difference below and above 3900 masl for the carbon isotope composition of modern and archaeological camelids. At altitudes above 3900 meters there is a major influence of C_3 compared to C_4 plants, due to factors such as higher mean annual precipitation (Samec et al., 2014). Hence, camelids pasturing at altitudes above 3900 masl would have access to a C_3-dominated flora environment, compared to lower altitudes where C_4 grasses would have been more abundant. This observation could potentially contribute to also identify the pasturing areas and mobility of domestic camelids through the study of their carbon isotope composition (Yacobaccio et al., 2009; Yacobaccio et al., 2010).

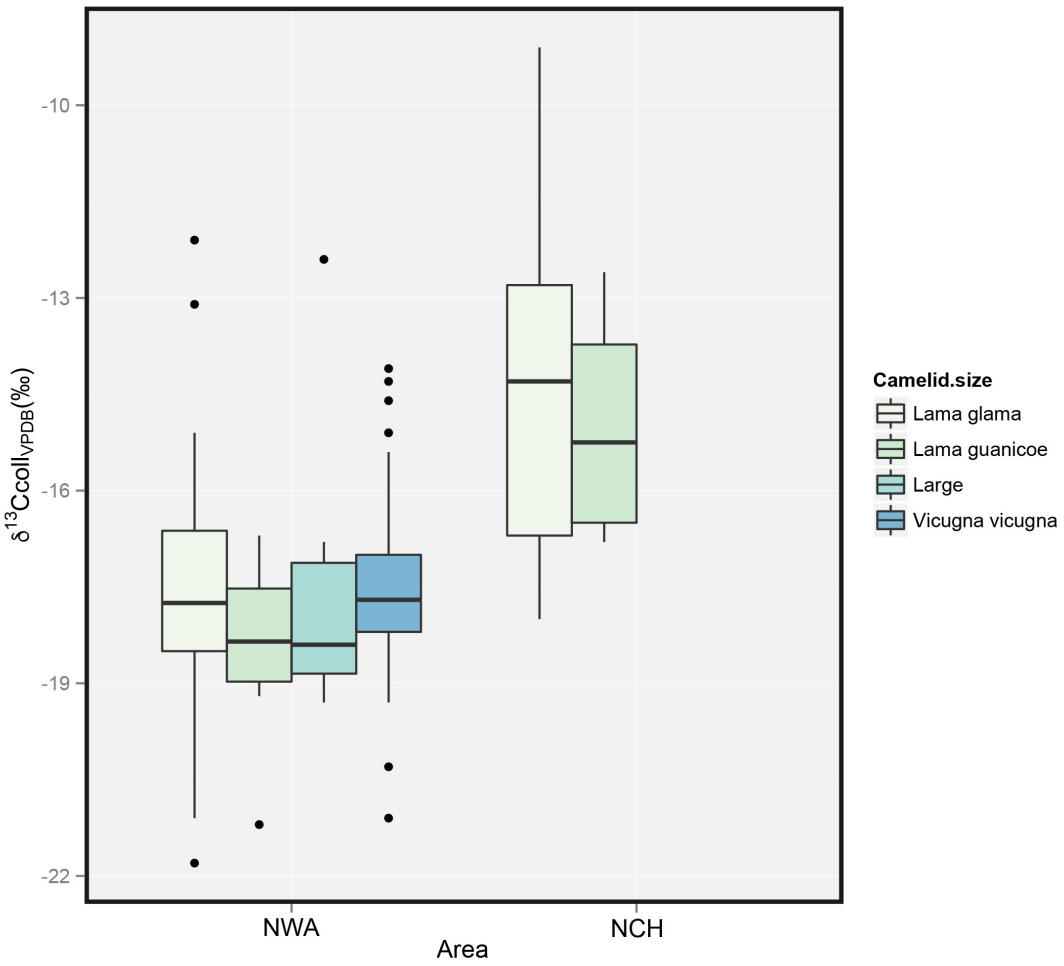


Figure 4.8. Boxplot showing $\delta^{13}C$ values for camelids from northwest Argentina (NWA) and northern Chile (NCH). NWA data was taken from Fernández and Panarello (1999-2001), Yacobaccio et al. (2009), Yacobaccio et al.(2010), Samec et al. (2013) and Samec.(2014). Northern Chile data was obtained in this study and taken from López et al. (2013).

Through considering these aspects and an evaluation of $\delta^{13}C$ values of the llamas analysed in this work, the data suggest that these animals could have been pasturing at different altitudes. This information has the real potential of giving new insights on human management of herd mobility for northern Chile. However, more detailed studies, such as incremental analyses of dentine, enamel and hair are needed in order to shed new light into the mobility of these animals. In addition, three camelids analysed in this work were particularly enriched in ^{13}C. They all come from the LIP cemetery of Quitor 6, and their values strongly suggest an input of C_4 plants in their diet. Since they date to the LIP, it is probable that these llamas were fed with maize.

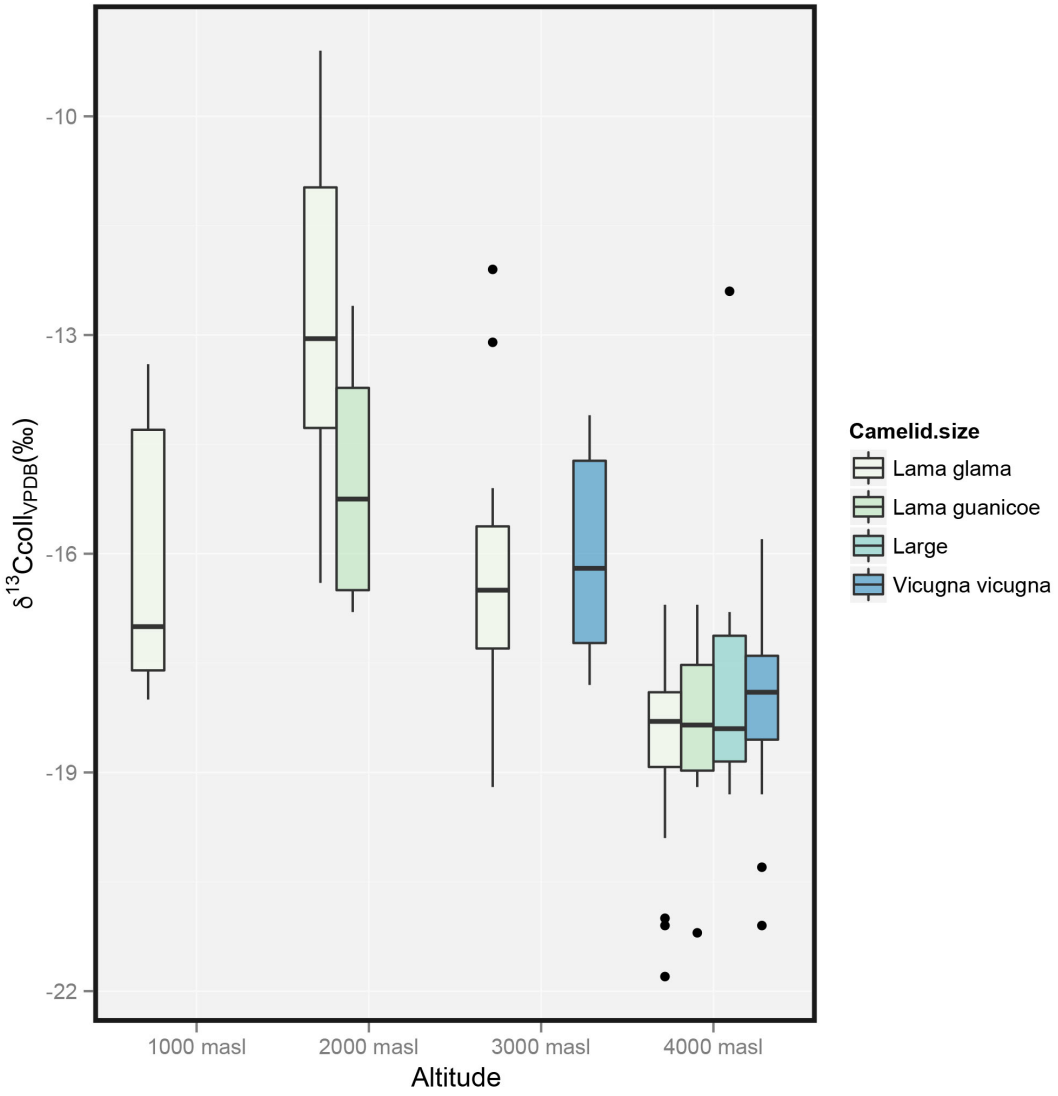


Figure 4.9. Boxplot showing $\delta^{13}C$ values for camelids from northwest Argentina and northern Chile by altitude. NWA data was taken from Fernández and Panarello (1999-2001), Yacobaccio et al. (2009), Yacobaccio et al.(2010), Samec et al. (2013) and Samec.(2014). Northern Chile data was obtained in this study and taken from López et al. (2013).

Chilean camelids also show higher $\delta^{15}N$ values when compared to those from northwestern Argentina. As seen in Figure 4.7 the llamas analysed here together with the Tulan 54 and 58 individuals (south of the Atacama salt lake – López et al., 2013) are more enriched in ^{15}N. Again, altitude could be playing an important role here. The results obtained both by Díaz et al. (2016) for northern Chile and by Samec et al.

(2015) for northwest Argentina show a negative correlation between the $\delta^{15}N$ values of plants and altitude. If the camelids were pasturing at higher altitudes it would be expected that they would show an isotopic composition depleted in ^{15}N.

4.6 Plants and animals isotope composition in northern Chile: A complex scenario for human palaeodiet reconstruction

The new carbon and nitrogen isotope results obtained in this research show the complexities that characterise the local ecology for northern Chile. Not only are the geography and extreme arid conditions of the Atacama affecting the plant isotope values of modern and archaeological plants, but also human intervention and its impact on the environment has had a great effect in their isotopic composition. Furthermore, the Pacific Ocean and the Humboldt Current that runs along the Chilean coast contributes even more difficulties to understanding the nitrogen composition of the marine fauna. This is clearly revealed by the significant variability in the trophic chain systems and the high biodiversity sustained by an intense upwelling system that characterise this marine system.

By comparing the archaeological values of fruits and crops in relation to animals is possible to see how diverse their isotope compositions are (Figures 4.10a, b). It is remarkable to see how the crops in general show higher $\delta^{15}N$ values than the terrestrial and especially the marine fauna (Figure 4.10a). At the same time, crops show high variability in their range of $\delta^{15}N$ values.

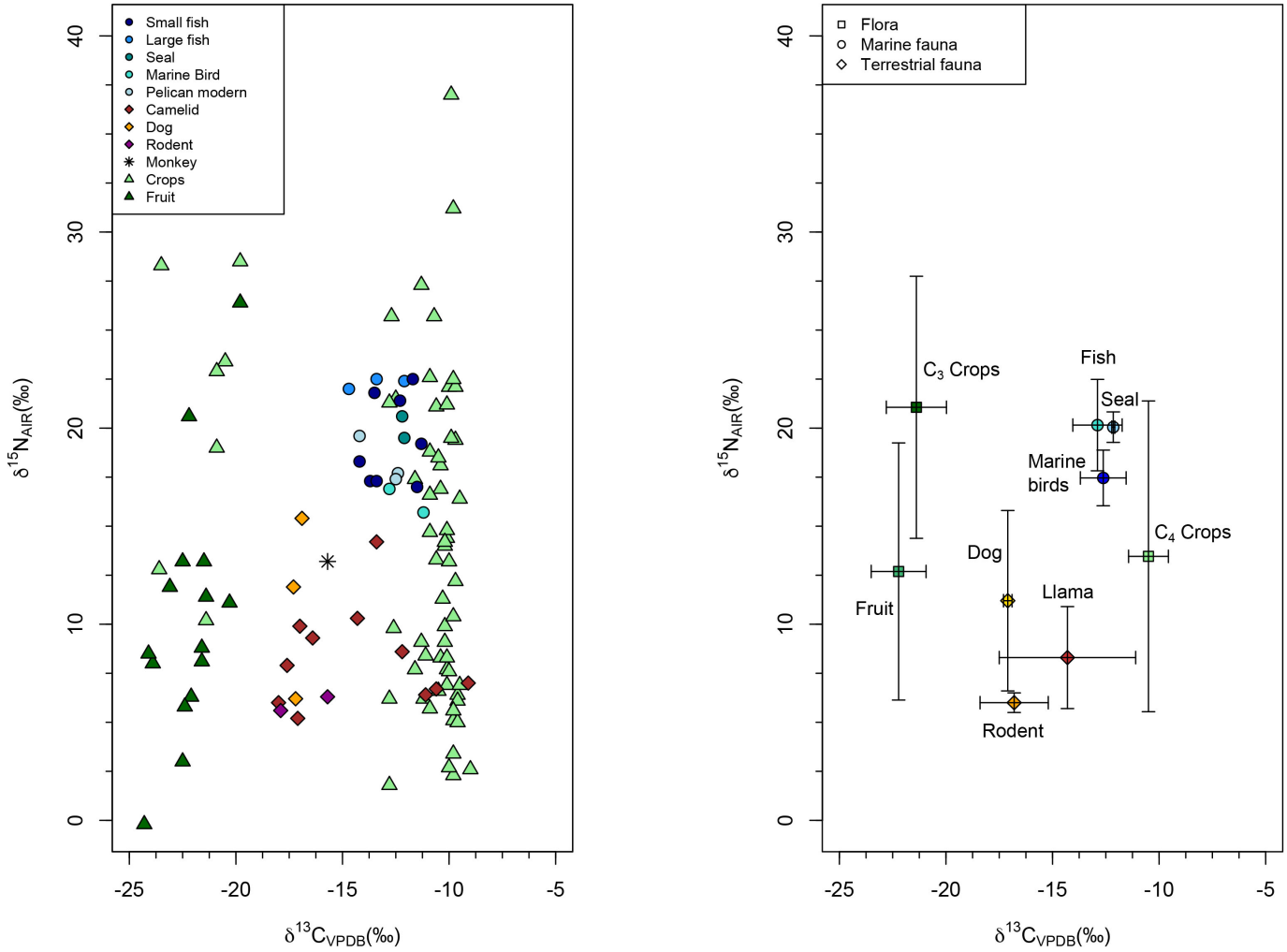


Figure 4.10. (a) Bivariate plot showing $\delta^{13}C$ and $\delta^{15}N$ values for archaeological plant (including fruits and crops) and animals (including terrestrial and marine fauna) from northern Chile. (b) Bivariate plot showing $\delta^{13}C$ and $\delta^{15}N$ mean and standard deviation values for archaeological plant (including fruits and crops) and animals (including terrestrial and marine fauna) from northern Chile.

Figure 4.10b shows the mean and standard deviations for the archaeological samples analysed here. In contrast to the previous graph (Figure 4.10a) the marine fauna appears with a more enriched in ^{15}N average and standard deviation values compared to the C_4 crops, although this is not the case for C_3 crops. Terrestrial fauna, on the other hand, shows lower nitrogen isotope values for rodents, followed by the llamas and finally the dogs at the very end.

In order to obtain a better understanding of northern Chile's isotopic ecology, Figure 4.11 shows the means and standard deviations of modern flora (including the results of this research and Díaz et al., 2016), ancient rodent faeces (Díaz, 2014), together with all the archaeological samples. This figure gives a clearer view of the isotopic composition of wild and domesticated plants and its relation to the terrestrial fauna. Modern C_3 and C_4 plants, together with ancient rodent faeces, show the expected values for carbon and nitrogen isotopes under the effects of the arid conditions, along with the possible influences of the altitudinal gradients. On the other hand, the archaeological crops and fruits reflect the impact of manuring practices, suggesting the complexity of agricultural activities in pre-Columbia northern Chile.

Coastal wild plants values suggest that sea bird guano accumulations at or near the coast can have an impact on their nitrogen composition, without any deliberate human intervention.

The consumption of any of these different resources, both wild and domesticated plants and animals, will have a considerable effect on the isotopic composition of humans. For example, not only the ingestion of marine fauna can increase the carbon and nitrogen isotopes of an individual but also the consumption of fertilised maize could lead to the same range of values.

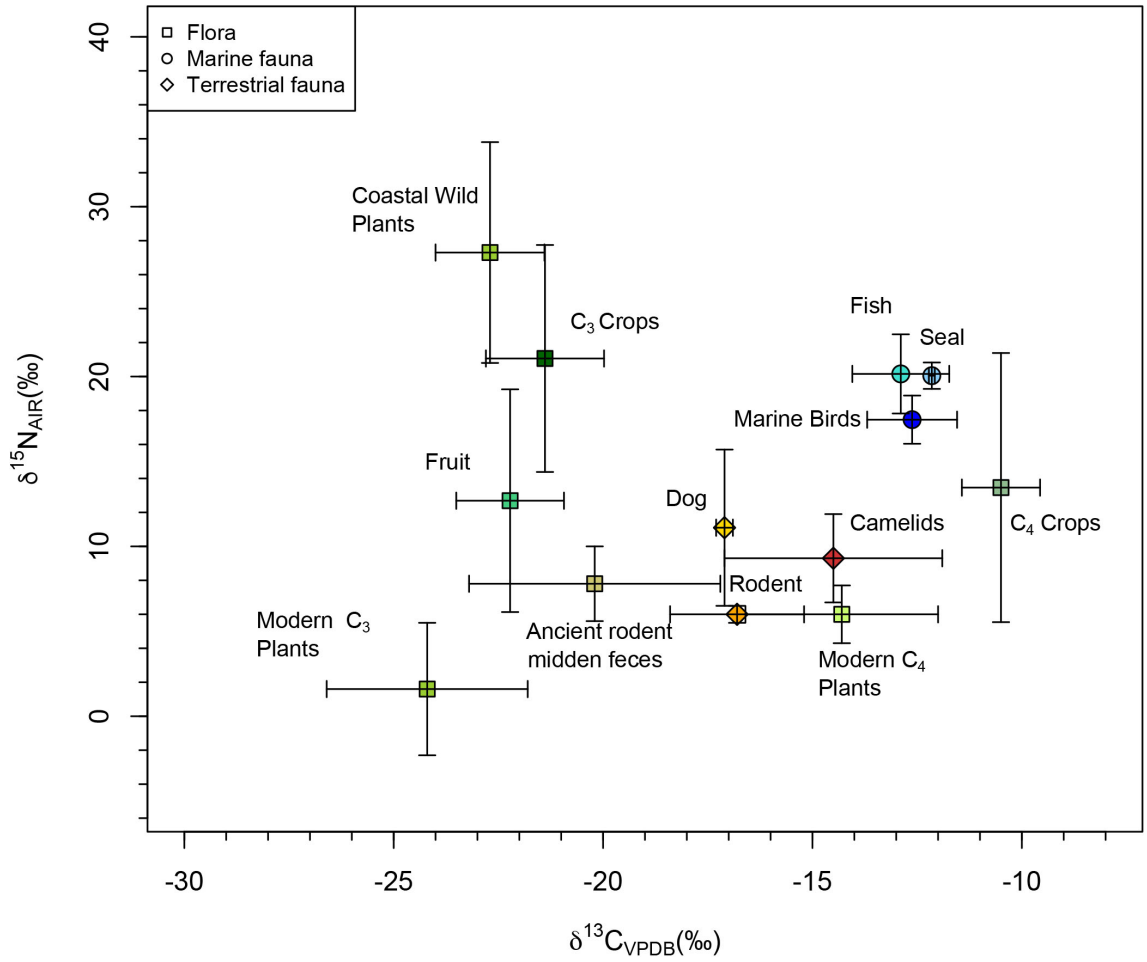


Figure 4.11. Bivariate plot showing $\delta^{13}C$ and $\delta^{15}N$ mean and standard deviation values for archaeological and modern plant (including fruits and crops) and animals (including terrestrial and marine fauna) from northern Chile obtained in this study and by Díaz (2014) and Díaz et al., (2016).

4.7 Conclusions

The reconstruction of local baselines is of great relevance for the study of human palaeodiet. As seen in this chapter many factors can play an important role on the isotopic composition of plants and animals. For instance, the geography of the area, temperature, water availability and altitude are going to directly affect the physiological adaptations of plants and consequently animals. These factors can lead to an increase or decrease in the carbon and nitrogen values of the local flora and fauna.

Carbon and nitrogen isotope composition of plants is quite complex and further studies are needed in order to study their adaptations in the Atacama Desert. No correlations were observed between altitude and $\delta^{13}C$ and $\delta^{15}N$ values, contrasting with the results obtained for the highlands of Arica (Tieszen and Chapman, 1992), but resembling the ones from northwest Argentina (Samec et al., 2015). Further research is needed in order to better understand the adaptation of the different C_3 and C_4 species to the arid Atacama.

One relevant and quite surprising result from this research was the remarkably high nitrogen isotope values for archaeological crop samples. Here, it is proposed that natural fertilisers, in this case seabird guano, were used in agricultural practices from at least from the LIP onwards. This is a crucial aspect to be considered when evaluating human diets during pre-Columbian times, since their use with crops can increase human $\delta^{15}N$ values significantly. Consequently, high nitrogen isotope values in humans caused by the consumption of fertilised crops could easily be confused with a marine diet. Future research on the subject is imperative in order to evaluate how much of the nitrogen present in the crops goes to the collagen composition of ancient human bone and dentine as well as keratin.

Terrestrial and marine fauna also show how important it is to develop a local baseline, considering they will vary again according to the different geographic and environmental conditions of the area. Camelids carbon and nitrogen isotopes are going to be directly affected by the area where they pasture. In addition to this, human intervention on the movement of domesticated camelids herds is also going to affect the isotopic composition of these animals, with variability depending on where they are taken for pasture, and also whether or not they are fed crops.

New studies are needed in order to complement the work done in this research. It is important to evaluate the altitudinal gradients and its relation to the isotopic profiles of different plant species of the Atacama Desert. This is crucial for understanding herbivore's diet, especially camelids.

It is thus possible to assert that this new baseline will contribute to a much better understanding of prehistoric human diet in northern Chile. The isotopic values of flora and fauna reported in this chapter are thus fittingly used in the reconstruction of human paleodiet presented in Chapter 5.

Chapter 5

Palaeodiet during the LIP: Insights on the associations between diet and cultural affiliation based on stable isotope analysis

As summarised in Chapters 1 and 3, the LIP was characterised by a high degree of independence and autonomy by the different cultural groups inhabiting the Atacama. Even though there was no central state governing the South Central Andes, these groups managed to maintain connections between them, through time and regardless of distance and geographic location (Núñez 1984; Pimentel 2012). The main driving force behind these connections was the exchange of goods, specifically of food products. Groups exchanged items along a vertical ecological gradient so that people inland had access to marine resources in exchange of maize or other crops (Núñez, 1984; Schiappacasse et al., 1989; Moragas, 1995; Pimentel, 2012). Hence, it has been assumed that the different cultural groups of northern Chile accessed food resources not locally available.

The access to different food items has been explained through mobility models (Murra, 1972, Núñez and Dillehay 1995) that do not have strong archaeological evidence supporting them. So the questions emerge:

1. What was the diet of the LIP people in the different cultural groups inhabiting the coast and inlands of the Atacama Desert?
2. Would it be possible to identify the so-called colonies or the *caravaneros* through their diet? Núñez (1984) proposes that colonies would have kept their diet traditions in foreign locations.
3. If so, it would be expected to see a considerable number of individuals having a typical highland diet in the lowlands.

4. At the same time, it is expected that *caravaneros* will show a great variability in their diet composition, assuming they consumed the foods present in each place visited, following their high mobility patterns (Núñez and Dillehay, 1995).

Following this, the main aim of this chapter is to characterise the human diet during the LIP for the Antofagasta, Atacama, and Tarapacá cultural groups analysing carbon and nitrogen isotopes on teeth, bone collagen and hair tissues. By characterising the diets of the local cultural groups there will be a better understanding of their economy and trade systems, evaluating the presence/absence of colonists or immigrants in the region. For achieving this aim the objectives of this chapter are: a) characterise and evaluate the dietary patterns at the individual level, including during infancy, the last 10 years of life and the last six months of life; b) determine if there are any significant differences in the isotopic composition of the tissues analysed by sex; c) compare the inter-group dietary composition.

5.1 Stable Isotope analysis in ancient human remains from northern Chile

New isotopic analysis have been carried out in the region, now including the coast of Antofagasta, the Atacama Oases, the Tarapacá cultural region and the Arica-Occidental Valleys region. For the Antofagasta-Taltal coast, analysis of individuals dating to the Formative Period show a strong emphasis on coastal resources (Pestle et al (2015), following a marine tradition extending back to the Archaic Period (Andrade et al., 2015). Fish consumption was suggested as well for the inland valleys of the Antofagasta region, in the middle course of the Loa River. Specifically, individuals of the San Salvador cemetery, dating to the Formative Period, located 110 km from the coast were analysed for stable isotope analysis of carbon and nitrogen (Torres-Rouff et al., 2012). Even though there is evidence of fish at the site, the average $\delta^{13}C_{coll}$ and $\delta^{15}N$ values are relatively low, with -16.8‰ and 12.5‰, respectively. These values

contrast dramatically with those from the Antofagasta and Taltal coast that are characterised by being close to -11‰ for carbon isotopes and higher than 22‰ for nitrogen isotopes (Andrade et al., 2015; Pestle et al., 2015).

Further inland, at approximately 200 km from the coast of Antofagasta, the Atacama Oases together with the upper course of the Loa River (*Alto Loa*) have also been studied for isotopic analysis on human remains. Most of these analyses ($\delta^{18}O$ and $^{87}Sr/^{86}Sr$) are focused on studying mobility during the Middle Period (Tiwanaku influence) (Knudson and Price, 2007; Knudson and Torres-Rouff, 2009; Knudson et al., 2014; Knudson et al., 2015) finding few non-local individuals. Carbon isotopes carried out in bone and enamel tissues from individuals dating to the Middle Period (Nado et al., 2012; Knudson et al., 2015) show mainly a mixed C_3-C_4 ingestion. New studies on bone collagen and apatite for the Middle Period have been published, showing a strong tradition of terrestrial and mixed C_3 and C_4 diets (Pestle et al., 2015; Torres-Rouff et al., 2015; Uribe et al., 2016). So far no evidence for marine foods has been found in the Atcama Oases (Schiappacasse et al., 1989; Costa Junqueira, 1998; Adán et al., 2004), consistent with the isotopic evidence (Pestle et al., 2015; Uribe et al., 2016).

For the Tarapacá cultural area, a few isotopic analyses were carried out on individuals dating to the Formative Period from the coastal sites of Pisagua (Aufderheide et al., 1994), Cañamo and Caleta Huelén (Santana et al., 2012). Following the same pattern seen in Antofagasta the coastal individuals of Tarapacá show quite enriched in ^{13}C and ^{15}N diets. Again the nitrogen isotopes are particularly high above 22‰.

For inland Tarapacá, the cemetery of Tarapacá 40 is the only one analysed for stable isotopes so far (Santana et al., 2012; Santana-Sagredo et al., 2015c). The results show carbon and nitrogen isotope values that are higher to those observed for the Atacama Oases and San Salvador, suggesting more fish consumption. However, this was not as important here as it was along the coast. There is also no evidence of

heavy reliance on maize during these periods of transition to agriculture (Santana-Sagredo et al., 2015c).

Research carried out for the LIP in northern Chile will be described in the following section

5.2 Diet during the LIP: What we know so far

The recent isotopic studies carried out in northern Chile have provided new insights on different aspects related to the LIP in Atacama and Tarapacá, particularly.

In the case of the Atacama cultural group, the Quitor 6 cemetery (Santana-Sagredo et al., 2015a) shows a local population that clearly follows the Atacama tradition retained from the Middle Period (Pestle et al., 2015; Pestle et al., 2016; Uribe et al., 2016). Here terrestrial resources dominate the diet, without incorporating any food resource from the coast. In this sense, the Atacama cultural groups appear to be quite homogeneous for the LIP with most of them presenting a mixed diet of C_3 and C_4 resources. No outlier individuals were observed in the sample studied (n=16). At the same time, the Quitor 6 burial offerings (Costa-Junqueira et al., 1988) suggest a quite local tradition, seen in the pottery, textiles, basketry and food offerings (llama feet, *algarrobo* seeds and cobs, maize cobs).

On the other hand, for the Tarapacá cultural groups, the Pica 8 cemetery (n=30) shows considerable variation in its isotopic composition (Santana-Sagredo et al., 2015a). Here it was possible to identify at least two main groups with similar high $\delta^{13}C$ values but with different nitrogen isotope compositions. Part of the group presents very positive values for their $\delta^{15}N$ around 20‰, assimilating to the nitrogen isotope signals observed for the coast of Antofagasta, Tarapacá and Arica (Santana et al., 2012; Pestle et al., 2015; Roberts et al., 2013; Diaz-Zorita Bonilla et al., 2016). The other individuals instead, show values around 14-15‰. These results are markedly higher that the ones observed for Quitor 6 (averaging 11‰). It is possible that these Pica 8

individuals might have ingested some amount of fish but it was not an important part of their diets.

Even though there is a marked local tradition, at least four individuals have non-local diets. Three of them show values that could be related to the *altiplano* following their depletion in ^{13}C and ^{15}N diets. They probably consumed a terrestrial diet (rodents and camelids) with C_3 crops such as potatoes and *quínoa* (Santana-Sagredo et al., 2015a). The fourth non-local individual shows in contrast clear connections with the coast, showing the highest $\delta^{15}N$ of the sample (24‰). In addition, this individual shows carbon apatite values for teeth and bone that do not suggest an ingestion of maize.

Other emblematic LIP cases of mobility are evidenced in the *Cementerio Oriente* of Quillagua. A total of 23 samples was analysed for carbon and nitrogen isotopes in bone collagen together with carbon in bone and tooth apatite (Santana-Sagredo et al., 2015b). The archaeological evidence of the cemetery suggests this was a place of connection between the Atacama and Tarapacá cultural groups (Agüero et al., 1999). Yet, the isotopic evidence clearly shows a greater connection with the Tarapacá cultural groups in terms of diet, closely resembling the isotopic composition found at Pica 8. Four non-local individuals were identified, being quite similar to the Pica 8 outliers. They show a more "*altiplano*" diet with quite low values for their $\delta^{13}C$ and $\delta^{15}N$.

From these three LIP cases in the Tarapacá region, the Atacama oases and Quillagua, new evidence rises in terms of the mobility and dietary patterns for northern Chile. The data suggest that without doubt mobility was happening during the LIP. However, more information is needed in order to better understand how was this occurring and how it affected the dietary patterns in other individuals of the period. So far there is no information about the Tarapacá groups from the coast, or from the Alto Loa next to the Atacama Oases. In this thesis, new samples from the Antofagasta coast, Atacama

Oases/Alto Loa and the Tarapacá groups (inlands and coast) are analysed, complementing the previous information obtained for the LIP.

5.3. Materials and Methods

5.3.1 Sampling and sites

A total of 134 individuals were selected for stable isotope analysis from different museums and university collections in Chile. Samples were obtained from the Instituto de Investigaciones Arqueológicas y Museo RP Gustavo Le Paige (San Pedro de Atacama), Museo Regional de Iquique (Iquique), Museo de Antofagasta (Antofagasta), Museo Nacional de Historia Natural (Santiago) and Departamento de Antropología-Universidad de Chile (Santiago).

It needs to be mentioned that there were some problems with sample collection. Firstly relatively few samples were taken from the Instituto de Investigaciones Arqueológicas (SPA), after changes in their sampling protocols for external and internal researchers. The politics of the Institution have been changed in order to respect the modern indigenous community and its ancestors. Previously, foreign researchers took a considerable amount of samples, destroying many skulls and leaving them literally with almost no teeth. For this reason, the number of samples taken had to be reduced. In addition, most of the human collections in this museum are skulls collected by the Belgian priest Gustavo Le Paige during the 1940s-1960s. This situation made the sample collection particularly difficult, since only in a few cases was possible to find skull fragments broken postmortem. A similar situation occurred in the Natural History Museum of Santiago. The collections were mainly skulls collected by the pioneer archaeologist Max Uhle in the 1910s.

The Museo Regional de Iquique holds many collections contributed by amateur archaeologists or consultancy activities during the last 4 decades. Unfortunately, because of the lack of government support the museum does not have the resources to create a proper system of collection management. Many of the skeletons and mummified bodies are in very bad preservation conditions. It was difficult to access the collections without a proper inventory, which did not exist at the time of sampling. In addition, many of the skeletons, mummies and archaeological objects lacked of information regarding their contexts. Thankfully, the Director of the museum together with an archaeologist specialised in the area helped immensely in finding the collections dating to the LIP.

For this reason, in many cases samples were taken from what was available. For example, when a mummy was found, only hair and tooth (where possible) samples were taken. Many of the samples taken are either teeth; bone and teeth; or bone, teeth and hair. A detailed list of the samples taken per individual divided by cultural association is presented in Tables 5.1.

A total of 134 individuals were sampled: eight individuals sample come from Antofagasta; 40 from the Atacama-Alto Loa Culture; and 85 are associated with the Tarapacá cultural groups, subdivided in Coast (n=30) and Inland (n=55).

5.3.2 The samples

Teeth (total n=62), bone (total= 67) and hair (total=42) samples were selected from the above mentioned sites (Table 5.1). All these different tissues were selected in order to compare different moments in the lives of individuals. This methodological approach would help to better understand changes in the diet through time, and its correlation with mobility. Tooth samples will reflect the diet consumed during enamel formation (Hillson, 1996; Turner et al., 2010). Enamel mineralisation occurs at different moments

during infancy depending on the type of tooth (Hillson, 1996). Once formed, enamel does not undergo isotopic change (Wright and Schwarcz, 1989). Thus tooth enamel keeps a record of the diet consumed during early moments in life. For instance, second and third molars start enamel formation at around 6 and 12 years old, respectively (Hillson, 1996). Bone provides information on the last 7 to 10 years of life of an individual, based on its slow rate of turnover, particularly for ribs (Hedges et al., 2007). Hair, on the other hand shows information about diet during the last months of life of an individual (O'Connell et al., 2001; Williams and Katzenberg, 2012). It is assumed that hair grows approximately one centimetre per month (O'Connell et al., 2001; Williams and Katzenberg, 2012).

Collagen and apatite fractions of bone were analysed. This was done with the aim of avoiding confusion on the carbon values coming from marine resources and C_4 plants, since they will tend to overlap, due to their enriched in ^{13}C compositions. $\delta^{13}C$ values from collagen are by themselves not the ideal tool for differentiating between these two types of resources, as they only reflect the protein fraction of diet (Ambrose and Norr, 1993). $\delta^{13}C$ values from apatite, on the other hand, reflect the whole diet consumed (Ambrose and Norr, 1993), being able to differentiate between the consumption of coastal resources and maize. Carbon isotope values more positive than -7‰ are indicative of C_4 resource consumption (Santana-Sagredo et al., 2015a).

Considering the excellent preservation of tissues in the Atacama Desert, due to the arid conditions (Clarke, 2006) together with the very scarce presence of water, it is unlikely that diagenesis affected the bones (Santana Sagredo et al., 2015a).

Only adults were considered in the analysis. Sex and age information was described in the containers of most of the museum and university collections. When this information was not available sex and age were estimated following Buikstra and Ubelaker standards (1994). Only three infants (6-8 years) together with one juvenile (15 years)

were included in the sample, all from Pica 8. Individual B0414 (6-8 years) was selected for radiocarbon dating together with isotopic analysis. Further details are given in Chapter 6.

Cultural Group	Location	Site	Sex	Age	Sample	Individual
Antofagasta	Coast	Auto Club	M	Adult	3RLM	AC 4627
Antofagasta	Coast	Auto Club	U	Adult	12º Rib	AC 4631A
Antofagasta	Coast	Auto Club	F	Adult	9º Rib, 3LUP	AC 4628.A
Antofagasta	Coast	Auto Club	M	Adult	10º Rib	AC 4638.c1
Antofagasta	Coast	Auto Club	M	Adult	Ulna	AC 4641
Antofagasta	Coast	Auto Club	U	Adult	12º Rib	AC5052B
Antofagasta	Coast	El Vertedero	M	Adult	3LUM, humerus	EVC1
Antofagasta	Coast	El Vertedero	F	Adult	Humerus	EV-C3
Atacama	Inland	Quitor 6	F	Adult	3RUM, skull	T07
Atacama	Inland	Quitor 6	M	Adult	2LLM	T11
Atacama	Inland	Quitor 6	F	Adult	12º Rib	T21
Atacama	Inland	Quitor 6	F	Adult	3RLM, 12º rib	T30
Atacama	Inland	Quitor 6	M	Adult	3LLM	T31
Atacama	Inland	Quitor 6	F	Adult	2RUM, 12º Rib	T34
Atacama	Inland	Quitor 6	M	Adult	2RLM	T35
Atacama	Inland	Quitor 6	F	Adult	3LUM, bone(not identified)	T40
Atacama	Inland	Quitor 6	F	Adult	3LUM	T47
Atacama	Inland	Quitor 6	M	Adult	3LUM, hand phalange	T51
Atacama	Inland	Quitor 6	F	Adult	Skull	T54
Atacama	Inland	Catarpe 1	M	Adult	2LUM	CAT1 885
Atacama	Inland	Catarpe 1	M	Adult	3LUM	CAT1 2396
Atacama	Inland	Catarpe 1	M	Adult	2LUM	CAT1 2406
Atacama	Inland	Catarpe 1	M	Adult	2LUM	CAT1 4849
Atacama	Inland	Catarpe 1	M	Adult	Skull	CAT1 764
Atacama	Inland	Catarpe 1	F	Adult	Skull	CAT1 763
Atacama	Inland	Catarpe 1	F	Adult	Skull	CAT1 2397
Atacama	Inland	Caspana	F	Adult	Skull	CAS 12
Atacama	Inland	Caspana	M	Adult	3LUM	CAS 16
Atacama	Inland	Caspana	F	Adult	Skull	CAS 61
Atacama	Inland	Caspana	F	Adult	Skull	CAS 66
Atacama	Inland	Toconce	F	Adult	Skull	TOC 76
Atacama	Inland	Toconce	M	Adult	3LUM	TOC 87
Atacama	Inland	Toconao Oriente	F	Adult	12º Rib	TO T1
Atacama	Inland	Toconao Oriente	F	Adult	Rib	TO-2

Atacama	Inland	Toconao Oriente	M	Adult	Rib	TO-3
Atacama	Inland	Toconao Oriente	M	Adult	Clavicle	TO-4
Atacama	Inland	Toconao Oriente	M	Adult	Rib	TO-5
Atacama	Inland	Toconao Oriente	F	Adult	12º Rib	TO-6
Atacama	Inland	Toconao Oriente	F	Adult	Hand phalange	TO-7
Atacama	Inland	Toconao Oriente	F	Adult	Rib	TO T8
Atacama	Inland	Toconao Oriente	M	Adult	Skull	TO-T9
Atacama	Inland	Toconao Oriente	M	Adult	Skull	TO-T11 C1
Atacama	Inland	Toconao Oriente	M	Adult	12º Rib	TO-12
Atacama	Inland	Toconao Oriente	F	Adult	Skull	TO-13
Atacama	Inland	Toconao Oriente	M	Adult	Skull	TO-14
Atacama	Inland	Toconao Oriente	F	Adult	Skull	TO-15
Atacama	Inland	Toconao Oriente	M	Adult	Skull	TO-16
Tarapacá	Coast	Caleta Huelen 11	F	Adult	Foot phalange	CH 11 F
Tarapacá	Coast	Caleta Huelen 11	M	Adult	Hand phalange	CH11 M
Tarapacá	Coast	Caletan Huelen 12	F	Adult	Metatarsal	CH12 F
Tarapacá	Coast	Caleta Huelen 12	M	Adult	Tarsus	CH12 M
Tarapacá	Coast	Pisagua-Uhle	F	Adult	Hair	PIS 252
Tarapacá	Coast	Pisagua-Uhle	M	Adult	2RLM	PIS 255
Tarapacá	Coast	Pisagua-Uhle	M	Adult	Hair	PIS 259
Tarapacá	Coast	Pisagua-Uhle	U	Adult	Skull	Pis 279
Tarapacá	Coast	Pisagua-Uhle	U	Adult	2RUM and skull	PSI 286
Tarapacá	Coast	Pisagua-Uhle	M	Adult	2LLM	PS 292
Tarapacá	Coast	Pisagua-Uhle	F	Adult	2RUM	PS 301
Tarapacá	Coast	Pisagua-Uhle	M	Adult	2LLM	PS 302
Tarapacá	Coast	Pisagua-Uhle	M	Adult	2LLM	PS 305
Tarapacá	Coast	Pisagua-Uhle	F	Adult	2RLM	PS 334
Tarapacá	Coast	Pisagua-Uhle	M	Adult	2RUM	PS 344
Tarapacá	Coast	Pisagua Gruta	U	Adult	2RUM	PS1 GC1
Tarapacá	Coast	Pisagua Gruta	U	Adult	2RUM, 5º rib, hair	PS1 GC2
Tarapacá	Coast	Pisagua Gruta	U	Adult	2LLM	PS1 GC3
Tarapacá	Coast	Pisagua 5	U	Adult	2LLPM, rib	PS5 C34
Tarapacá	Coast	Pisagua Hospital	U	Adult	Rib	Pis Hosp S6
Tarapacá	Coast	Pisagua Hospital	U	Adult	Tibia	Pis Hosp S62

Tarapacá	Coast	Los Verdes 1	U	Adult	2PM	LV1- C77
Tarapacá	Coast	Los Verdes 1	M	Adult	1PM, hair	LV1- C333
Tarapacá	Coast	Los Verdes 5	M	Adult	12º Rib	LV5-243
Tarapacá	Coast	Patache Q	M	Adult	2RLPM, hair	PATQ-C2
Tarapacá	Coast	Bajo Molle Edificio Armada	M	Adult	Rib	BM C130
Tarapacá	Coast	Bajo Molle 1	F	Adult	3LUM, hair	BM1 C153
Tarapacá	Coast	Bajo Molle 1	U	Adult	2RLPM	BM1 C151
Tarapacá	Coast	Bajo Molle Edificio Armada	M	Adult	2RUP, hair	BM1 Ed Ar. C189
Tarapacá	Coast	Iquique-Calle Alessandri	M	Adult	2UM, 12º rib	Ca Al C26
Tarapacá	Inland	Iquique-Calles Tarapacá-Labbe	U	Adult	Rib	Re-Tar Lab C175
Tarapacá	Inland	Tarapacá pueblo	M	Adult	Hand phalange	Re-Tar M1
Tarapacá	Inland	Tarapacá pueblo	F	Adult	4º rib	SLT C121
Tarapacá	Inland	Pica 37	F	Adult	Rib	PICA 37 C2
Tarapacá	Inland	Pica 37	M	Adult	Skull	P37 C4
Tarapacá	Inland	Pica 8	F	Adult	Hair	P8 B0410
Tarapacá	Inland	Pica 8	F	Adult	Hair, 2LPM	P8 B0413
Tarapacá	Inland	Pica 8	M	6-8yrs	Rib	P8 B0414
Tarapacá	Inland	Pica 8	M	Adult	Hair	P8 B0415
Tarapacá	Inland	Pica 8	F	Adult	Hair, 2LM	P8 B0419
Tarapacá	Inland	Pica 8	F	Adult	Hair, 3UM	P8 B0420
Tarapacá	Inland	Pica 8	F	Adult	Hair, 3LM	P8 B0421
Tarapacá	Inland	Pica 8	F	Adult	Rib	P8 B0422
Tarapacá	Inland	Pica 8	F	Adult	Hair	P8 B0423
Tarapacá	Inland	Pica 8	F	Adult	Hair, 2UM	P8 B0424
Tarapacá	Inland	Pica 8	F	Adult	Hair	P8 B0425
Tarapacá	Inland	Pica 8	F	Adult	2LM	P8 B0426
Tarapacá	Inland	Pica 8	M	Adult	Hair, 2UM	P8 B0427
Tarapacá	Inland	Pica 8	F	Adult	Hair, 3UM	P8 B0428
Tarapacá	Inland	Pica 8	F	Adult	Hair	P8 B0430
Tarapacá	Inland	Pica 8	M	Adult	Hair, 3UM	P8 B0431
Tarapacá	Inland	Pica 8	F	Adult	Hair, 3UM	P8 B0432
Tarapacá	Inland	Pica 8	F	Adult	Rib, hair	P8 B0433
Tarapacá	Inland	Pica 8	M	Adult	Hair	P8 B0435
Tarapacá	Inland	Pica 8	F	Adult	Rib	P8 B0438
Tarapacá	Inland	Pica 8	F	Adult	Hair, 3UM	P8 B0439
Tarapacá	Inland	Pica 8	M	Adult	Hair, 2UPM	P8 B0440
Tarapacá	Inland	Pica 8	M	Adult	Hair, 2LM	P8 B0441
Tarapacá	Inland	Pica 8	F	Adult	Rib, hair	P8 B0442
Tarapacá	Inland	Pica 8	M	Adult	Rib	P8 B0444
Tarapacá	Inland	Pica 8	M	Adult	Hair, 2UM	P8 B0447

Tarapacá	Inland	Pica 8	M	Adult	Rib	P8 B0449
Tarapacá	Inland	Pica 8	F	Adult	Skull	P8 B0451
Tarapacá	Inland	Pica 8	F	Adult	Hair, 3UM	P8 B0453
Tarapacá	Inland	Pica 8	M	Adult	Rib	P8 B0455
Tarapacá	Inland	Pica 8	M	Adult	Hair	P8 B0460
Tarapacá	Inland	Pica 8	F	Adult	Hair	P8 B0462
Tarapacá	Inland	Pica 8	F	Adult	Hair, 3UM	P8 B0463
Tarapacá	Inland	Pica 8	F	Adult	Hair, 2UM	P8 B0468
Tarapacá	Inland	Pica 8	M	Adult	Hair	P8 B0469
Tarapacá	Inland	Pica 8	F	Adult	Hair	P8 B0470
Tarapacá	Inland	Pica 8	M	Adult	3LUM	P8 B0471
Tarapacá	Inland	Pica 8	F	Adult	2LUM	P8 B0473
Tarapacá	Inland	Pica 8	M	Adult	Rib, 3M, hair	P8 B0476
Tarapacá	Inland	Pica 8	F	Adult	1LLPM, rib	P8 B0478
Tarapacá	Inland	Pica 8	F	Adult	3LM	P8 B0483
Tarapacá	Inland	Pica 8	F	Adult	Hair	P8 B0485
Tarapacá	Inland	Pica 8	F	Adult	2LUM	P8 B0490
Tarapacá	Inland	Pica 8	M	Adult	Hair, 2LM	P8 B0493
Tarapacá	Inland	Pica 8	U	6-8 yrs	2LUM	P8 B0494
Tarapacá	Inland	Pica 8	F	15 yrs	2LUM	P8 B0495
Tarapacá	Inland	Pica 8	U	8 yrs	Rib	P8 B0498
Tarapacá	Inland	Pica 8	U	Adult	Hair	P8 B0509
Tarapacá	Inland	Pica 8	M	Adult	3LLM	P8 B0513
Tarapacá	Inland	Pica 8	M	Adult	Rib, hair	P8 B0796
Tarapacá	Inland	Cementerio Oriente	M	Adult	2LLM	02QUI01 CTX2
Tarapacá	Inland	Cementerio Oriente	F	Adult	3LLM	02QUI01 CTX3

Table 5.1. Samples information by site, location cultural group, sex, age, type of sample and individual number, where F=Female, M=Male, 1PM= First premolar, 2PM= Second premolar, 2RLPM= Second right lower premolar, 2LLPM= Second left lower premolar, 2LLM= Second left lower molar, 2RUM= Second right upper molar, 2LUM= Second left upper molar, 2UM= Second upper molar, 3LLM= Third left lower molar, 3RLM= Third right lower molar, 3LUM= Third left upper molar, 3UM= Third upper molar.

Ribs (mainly 12th ribs) were the main bones selected for the isotope analysis. If ribs were not available, hand or foot phalanges were taken. However, preference was given to fragments of post mortem broken bone when available. This was done in order to avoid destroying any other bones that could give relevant bioanthropological information. Where possible, second and third molars were sampled alongside bone. When these were not available, premolars were selected. These teeth all form after the first six years of life (Hillson, 1996); thus, there should be no breastfeeding effects on their isotope composition (Fogel et a., 1989; Katzenberg and Pfeiffer, 1995).

Hair samples of ca. 6cm total length were taken from the very root of the hair against the scalp. Hair was collected only when available in the skulls of the different individuals samples. However, Individuals showing complex hairstyle (i.e. braids) were avoided.

5.3.3 Methodology

Bone collagen was extracted using a modified version of the Longin method (1971), as for the faunal materials (Chap 4). Hair keratin was prepared following the protocol in O'Connell and Hedges (1999). First, hair was rinsed in milli-Q water for 30 minutes in an ultrasonic bath. It was then rinsed twice in a solution of 2:1 chloroform methanol for 30 minutes in an ultrasonic bath. Then it was rinsed in milli-Q water, in order to remove any solvent residue. Samples were left in the fume hood overnight. Once dried the hair lengths were cut every 1 cm from the root to the tip (6 centimetres were considered in total). Each bundle of hairs of 1 cm was then weighed (1 mg) and placed in tin capsules.

The same standards were used for bone collagen and hair. The in-house standards Alanine ($\delta^{13}C$= -26.9‰; $\delta^{15}N$=-1.63‰), and bovine liver ($\delta^{13}C$= -24.4‰; $\delta^{15}N$=7.76‰), and seal collagen ($\delta^{13}C$= -13.3‰; $\delta^{15}N$=17.3‰) were used for calibrating the carbon and nitrogen isotope measurements. The international IAEA-C6 ($\delta^{13}C$= -10.4‰) standard was also included for the calibration of carbon isotope values, assuming a high ingestion of C_4 resources in northern Chilean populations. Samples were analysed in duplicate (only for bone collagen) in a SER-CON 20/22 continuous flow ratio mass spectrometer coupled with an elemental analyser at the RLAHA of the University of Oxford. Precision was calculated in ±0.1‰ for $\delta^{13}C$ and ±0.3‰ for $\delta^{15}N$, based on multiple measurements of the standards.

Bone apatite was pre-treated following Smith's protocol (2005) for unfossilized/recent bone. An amount of 10 mg of bone apatite was reacted in sodium hypochlorite (1.5% v/v) for 3 hours in order to remove the organic fraction. The sample was then rinsed and centrifuged three times with milli-Q water. Afterwards, 0.1 M acetic acid was used to remove secondary carbonates. Samples were immersed in the acid solution for only 5 minutes, and then rinsed and centrifuged again with milli-Q water. Samples were freeze-dried over night. The isotope analyses of carbon (run in duplicate) were carried out in the Stable Light Isotope Laboratory of the University of Cape Town. The machine used was a Finnigan MAT 252 mass spectrometer coupled to a Gas bench II. International standards NBS 18 and NBS 19 together with internal marble standards were used for calibrating the results. The precision for carbon isotopes was estimated as 0.15‰.

Enamel apatite was pre-treated following the procedures presented by Sponheimer (1999). This protocol is similar to that for bone apatite, but differs in the timing. Tooth enamel was washed in 1.5% (v/v) sodium hypochlorite solution for 30 minutes. In contrast to bone apatite, the samples were left for 10 minutes in 0.1 M acetic acid, to be then rinsed and centrifuged in milli-Q water. Samples were freeze-dried overnight and then analysed in the Stable Light Isotope Laboratory of the University of Bradford. Carbon isotopes were measured in a Thermo Finnigan Delta V Advantage mass spectrometer coupled to a Gasbench II. The international standards CO-1 and CO-8 together with Merck $CaCO_3$ were used for calibrating the results. Precision for the carbon isotopes results was 0.1‰.

Descriptive and inferential statistics were used for analysis. Shapiro Wilk tests were applied in order to evaluate normality. When two groups were compared a Mann-Whitney Wilcoxon test was applied. Kruskal Wallis, Multiple Comparison Test after

Kruskal Wallis and ANOVA tests were performed when comparing more than two groups. Both tests (Kruskal Wallis and ANOVA) were used to compare the results. All the statistical analyses were run in R: The R Project for Statistical Computing (2003).

5.4 Results

5.4.1 Bone collagen and apatite

Detailed results for each individual analysed here are presented in Appendix 5.2 and shown in Figure 5.1.

A total of 57 samples had acceptable C/N ratios, falling in the range expected for good collagen preservation (DeNiro, 1985; Ambrose, 1990). Six samples were rejected for having C/N ratios outside this range, while four did not have collagen.

Descriptive statistics for $\delta^{13}C_{coll}$ and $\delta^{15}N$ divided by cultural group are presented in Table 5.2. The highest $\delta^{13}C_{coll}$ values were observed for the Inland Tarapacá groups, with a mean of -10.2±2.1‰, while the Atacama-Alto Loa groups showed the lowest values, averaging -14.1±1.1‰. The most enriched and depleted carbon isotope compositions were again reported for the same cultural groups with -7.9‰ and -16.6‰ for Tarapacá Inland and Atacama, respectively. As expected, the Antofagasta and Tarapacá coastal groups show positive $\delta^{13}C_{coll}$ values.

Nitrogen isotopes are quite enriched in ^{15}N, especially for the two coastal groups with means of 25.0±2.2‰ and 25.5±4.0 for Tarapacá Coast and Antofagasta, respectively. The Tarapacá Inland group also shows high results with a mean of 17.8±4.0‰. At the same time, this group shows high variability in its $\delta^{15}N$ values ranging from 12.6‰ to 24.2‰. In contrast, the Atacama group presented the lowest mean, 11.9±1.7‰.

Figure 5.1a clearly shows the variability in the $\delta^{13}C_{coll}$ and $\delta^{15}N$ results for the Tarapacá Inland group, as well as the more homogenous distribution of the Atacama-Alto Loa

group. The two coastal groups show the highest $\delta^{15}N$ values, with a small number of Tarapacá Coast individuals having a similar isotopic composition to the Tarapacá Inland group.

Bone apatite results show similar trends to those observed for carbon collagen, following an analogous distribution by cultural group in its values (Figure 5.2b). Again, the highest $\delta^{13}C_{ap}$ values were reported for Tarapacá inland with a mean of -6.7±3.5‰. However, it was also this group that showed the lowest results for $\delta^{13}C_{ap}$ with a minimum of -13.3‰, even more negative than the minimum of the Atacama-Alto Loa group (-11.6‰). On the other hand, the coastal groups presented very similar means of -9.2±1.5‰ and -9.1±1.3‰ for the Tarapacá Coast and Antofagasta groups, respectively.

Cult Gp	**δ^{13}Cap-enamel**				**δ^{13}Cap-bone**				**δ^{13}Ccoll-bone**				**δ^{15}N-bone**			
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min
TC	-7.4	2.1	-3.0	-12.9	-9.2	1.5	-5.7	-11.1	-11.7	1.2	-9.2	-13.7	25.0	2.2	27.4	19.0
TI	-5.5	3.6	0.7	-11.9	-6.7	3.5	-3.6	-13.3	-10.2	2.1	-7.9	-15.8	17.8	4.0	24.2	12.6
ANT	-8.2	1.4	-6.6	-9.2	-8.1	0.8	-6.7	-8.9	-11.8	0.3	-11.3	-12.1	25.5	0.5	26.1	24.6
ATA	-6.9	2.0	-2.1	-9.8	-9.1	1.3	-6.3	-11.6	-14.1	1.1	-11.6	-16.6	11.9	1.7	15.4	7.3

Table 5.2. Descriptive statistics for carbon and nitrogen isotopes from enamel apatite, bone apatite and collagen divided by cultural groups where TC=Tarapacá Coast, TI= Tarapacá Inland, ANT= Antofagasta and ATA=Atacama.

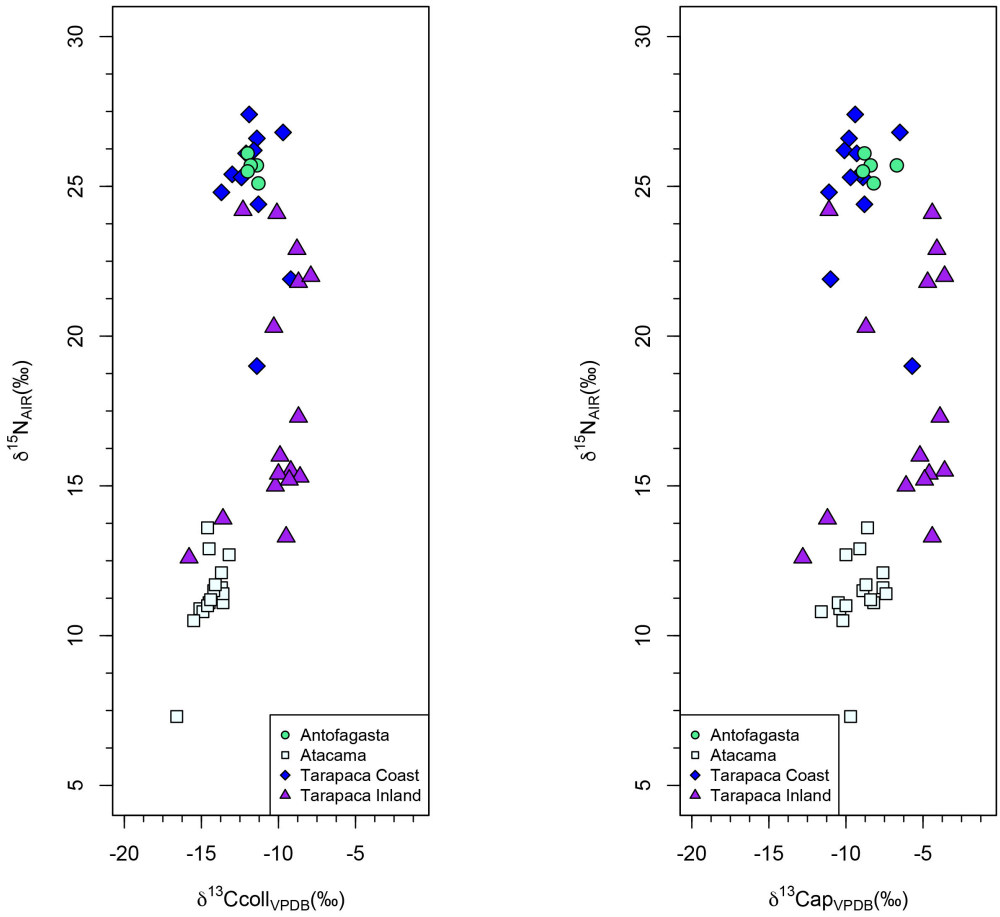


Figure 5.1. (a) Bivariate plot for $\delta^{13}C_{coll}$ and $\delta^{15}N$ of bone collagen samples from northern Chile cultural groups Antofagasta, Atacama, Tarapacá Coast and Tarapacá Inland (b) Bivariate plot for $\delta^{13}C_{ap}$ and $\delta^{15}N$ of bone apatite samples from northern Chile cultural groups Antofagasta, Atacama, Tarapacá Coast and Tarapacá Inland.

Values obtained for carbon collagen, apatite and nitrogen were tested for normality in each cultural group. Only the values for the Inland Tarapacá group were not normally distributed ($\delta^{13}C_{coll}$ W= 0.8987, p<0.05; $\delta^{13}C_{ap}$ W= 0.8563, p<0.05; $\delta^{15}N$ W=0.9373, p<0.05). There were no significant differences when comparing (Kruskal-Wallis; ANOVA) the $\delta^{13}C_{coll}$, $\delta^{15}N$ and $\delta^{13}C_{ap}$ values by sex in each of the cultural groups analysed here ($\delta^{13}C_{coll}$, p>0.05; $\delta^{15}N$, p>0.05; $\delta^{13}C_{ap}$, p>0.05).

Bone collagen for $\delta^{13}C$ values only showed significant differences when the Atacama-Alto Loa cultural group was compared with the Antofagasta, Tarapacá Coast, and Tarapacá Inland groups (Kruskal Wallis, chi-square=29.85, $p<0.05$; ANOVA, F-value=24.0, $p<0.05$).

The same situation occurred when nitrogen isotopes were compared. The Atacama-Alto Loa group was significantly different to the three other groups, but the Tarapacá Inland and Coast groups also differed significantly (Kruskal Wallis, chi-square= 40.52, $p<0.05$; ANOVA, F-value=70.87, $p<0.05$).

When carbon apatite values were compared between the cultural groups, significant differences were observed for the Tarapacá Inland and Atacama-Alto Loa groups, as well as for the Tarapacá Inland and Tarapacá Coast groups (Kruskal Wallis, chi-square= 11.23, $p<0.05$; ANOVA, F-value=6.52, $p<0.05$).

5.4.2 Tooth enamel

Descriptive statistics for $\delta^{13}C_{ap}$ from tooth enamel are presented in Table 5.2. A general trend is observed for these values, being higher than those observed for bone apatite (Figure 5.2). Tarapacá Inland presents the most enriched in ^{13}C composition with a mean of -5.5±3.6‰, followed by the Atacama-Alto Loa Cultural group showing a mean of -6.9±2.0‰. The lowest averages were reported for the two coastal groups, with -7.4±2.1‰ for Tarapacá Coast, and -8.2±1.4‰ for Antofagasta. The results for Tarapacá Inland were quite high, reaching figures above 0‰ with a maximum of 0.7‰. The Atacama-Alto Loa group as well as the Tarapacá Coast group also presents positive values with maxima of -2.1‰ and -3.0‰, respectively. Significant differences were observed only between the Atacama-Alto Loa and Tarapacá Inland groups (Kruskal Wallis, chi-square=12.12, $p<0.05$; ANOVA, F-value= 5.08, $p<0.05$).

Figure 5.2 presents boxplots for the carbon isotope values obtained from bone apatite and tooth enamel. Enamel tends to show higher results when compared to bone. However, significant differences were only observed between the tooth enamel and bone apatite of the Tarapacá Coast group (Mann Whitney, W=26, $p<0.05$).

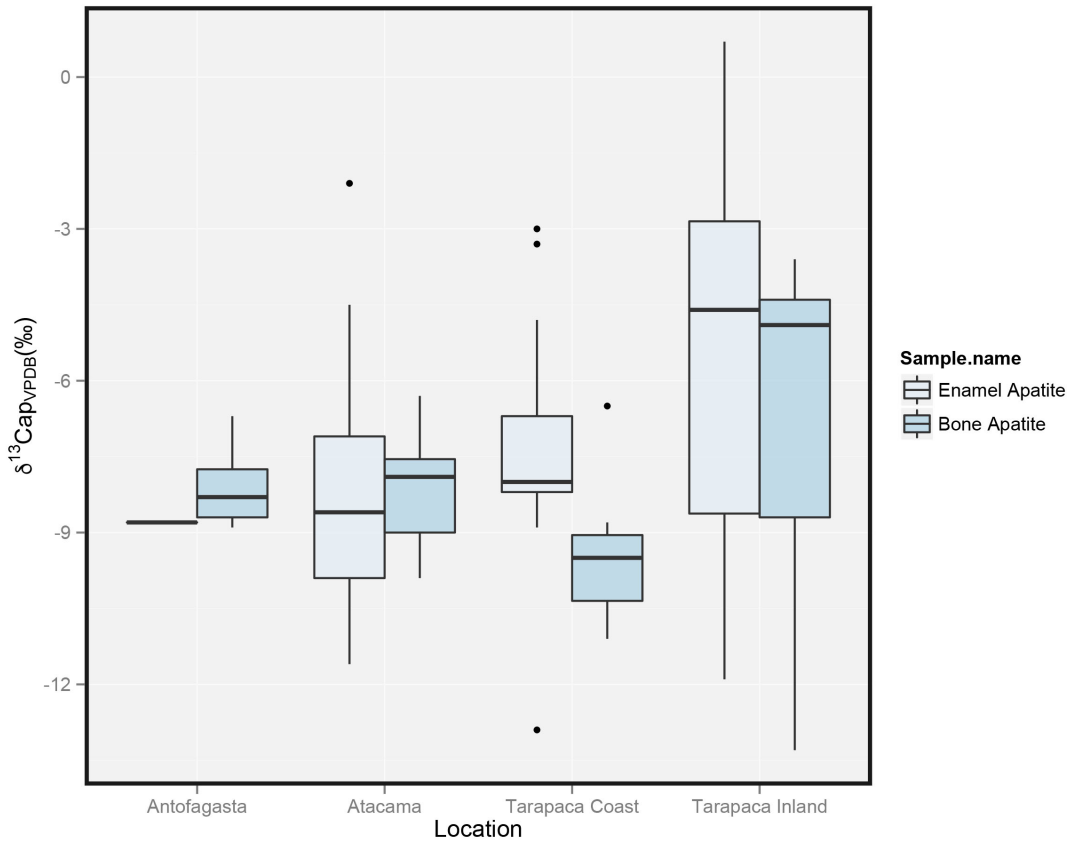


Figure 5.2. Boxplot showing tooth enamel and bone apatite $\delta^{13}C_{ap}$ values by cultural group.

5.4.3 Hair

Hair results are presented per individual in Figures 5.3a-b, 5.4a-b, 5.5a-b, 5.6a-b and 5.7a-b.

All had acceptable C/N ratios, falling in the range expected (2.9-3.8) for hair (O'Connell and Hedges, 1999). Unfortunately, results obtained for the 5th month before death of individual B0432, as well as individuals B0463 and B0485 for their 6th month, were lost due to problems with the mass spectrometer. The results obtained were altered and no additional samples were available to repeat the measurements.

The figures are divided in carbon and nitrogen isotopes, showing the variation in isotope values in the six months before death. Inland Tarapacá was represented only by the Pica 8 cemetery. For the Tarapacá Coast the sites analysed were Bajo Molle, Los Verdes, Patache and Pisagua. Given the site's previously demonstrated spatial structure (Santana-Sagredo et al. 2015a), the Pica 8 results were divided by sector (D,G,I and other sectors) (Figures 5.3a-b, 5.4a-b, 5.5a-b and 5.6a-b, respectively). All the coastal results were plotted together.

Pica 8's sector D shows a clear grouping of values for carbon isotopes around -10 and -11‰ (Figure 5.3a). Two cases are worth mention: individuals B0415 and B0427. The first shows a dramatic drop in its $\delta^{13}C_{coll}$ value by the fourth month before death. It is not clear if this could be a problem with the mass spectrometer, so that this data point remains questionable. Individual B0427 shows the lowest $^{13}C_{coll}$ results during the six months before death. Its $\delta^{13}C$ values increased during the four and three months of life, then decreased during the last two months of life.

For nitrogen isotopes (Figure 5.3b), there is also a grouping of values around 15‰. Again, individual B0451 shows a drop in its values during the fourth month before death. Individuals B0423 and B0441 contrast to the rest of sector D by showing more high $\delta^{15}N$ results. Both suffered drops in their nitrogen isotope composition values, however this was more marked for individual B0441.

Sector G also shows a grouping around -10‰ for carbon isotopes (Figure 5.4a). However, individuals B0425 and B0431 present lower results. Individual B0431 presents the lowest $\delta^{13}C$ values of Sector G, showing as well a remarkable drop during the 5th month of life that resembles that observed for individual B0415. Figure 5.4b

shows that individuals of sector G tend to group around 15‰ for nitrogen isotopes. The only exception here is individual B0463 with values close to 20‰. Individual B0431 presents again a dramatic decline in its values for the 5th month before death.

Sector I presents again carbon isotope values grouped around -10‰ (Figure 5.5a). Individuals B0424 and B0428 show the lowest results close to -12 and -13‰. In contrast to the previous figures, Figure 5.5b shows a clear grouping of the individuals above 20‰ for nitrogen isotopes. Individual B0424 shows the more positive values, above 25‰ during its 5th and 4th months before death. Individual B0428 presents the opposite the situation with a δ^{15}N value of 15‰, ca. 10‰ lower than individual B0424.

Figures 5.6a and 5.6b show the remaining sectors from Pica 8 (A, B, E, F, O and 'other' sectors). For carbon isotopes the results tend to group again around -10‰. Nevertheless, there are three individuals more enriched in ^{13}C, falling close to -8‰. Individual B0509 shows the lowest result with values that slightly dropped from approximately -14‰ to -16‰ during its last months of life.

Nitrogen isotopes on the other hand, show a quite variable scenario with individuals ranging from approximately 13‰ up to 25‰. Individual B0509 also presents lower δ^{15}N values during its two last months before death.

Coastal individuals are represented in figures 5.7a and 5.7b. Carbon isotopes show a very variable distribution with individuals ranging from -10‰ to -15‰. The highest values are observed for the two Bajo Molle individuals 153 and 189, with results around -10‰. The more negative results are reported for individual Los Verdes A333, around -15‰.

Figure 5.7b shows most of the individuals quite enriched in ^{15}N, with $\delta^{15}N$ values above 20‰. Individual Bajo Molle 153 shows a gradual increment in its isotopic composition during the 6 months before death, showing enrichment in ^{15}N close to 5‰. In contrast, individual Bajo Molle 189 comprises the lowest results for $\delta^{15}N$ of the group, having quite homogenous values through time, of around 14‰.

Pica 8	**δ^{13}C-keratine**				**δ^{15}N-keratine**			
	Mean	SD	Max	Min	Mean	SD	Max	Min
Month 1	-10.8	1.9	-8.1	-16.1	18.3	4.1	25.6	12.6
Month 2	-10.6	1.8	-8.2	-15.9	18.3	4.2	25.6	12.6
Month 3	-10.5	1.6	-8.2	-15.1	18.2	4.3	25.9	12.7
Month 4	-10.7	1.9	-7.9	-15.8	18.1	4.7	25.9	6.8
Month 5	-10.8	2.3	-8.1	-18.5	18.0	4.8	26.6	7.9
Month 6	-10.8	1.9	-8.1	-16.7	18.3	4.5	26.2	12.1

Table 5.3. Descriptive statistics for carbon and nitrogen isotopes from hair divided per months before death, for Pica 8 individuals.

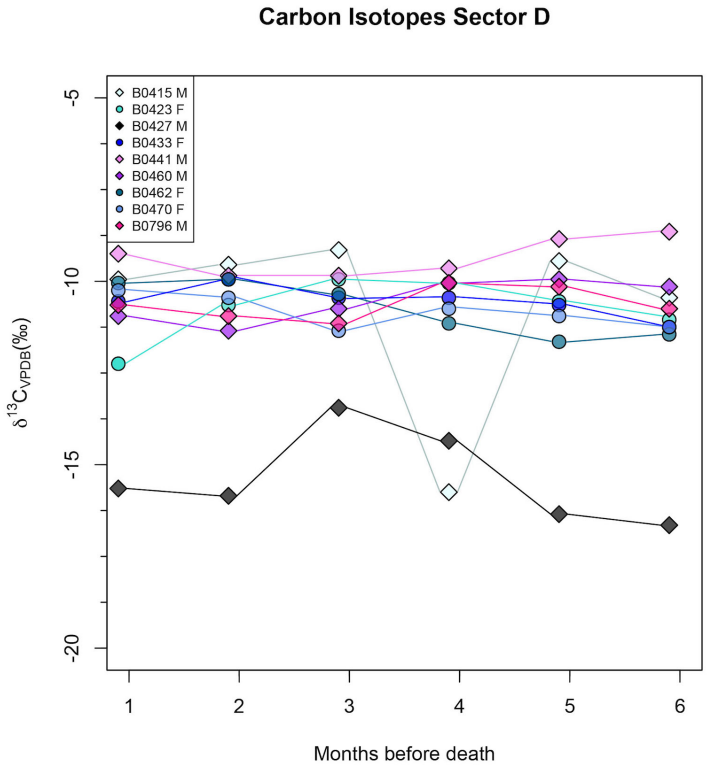
Tarapacá Coast	**δ^{13}C-keratine**				**δ^{15}N-keratine**			
	Mean	SD	Max	Min	Mean	SD	Max	Min
Month 1	-12.8	2.0	-9.5	-15.4	21.9	3.9	26.5	14
Month 2	-12.7	2.0	-9.5	-15.5	21.3	4.0	26.3	13.8
Month 3	-12.6	1.9	-9.6	-15.2	21.2	4.1	26.0	13.9
Month 4	-12.5	1.8	-9.6	-14.5	21.0	4.3	26.4	13.7
Month 5	-12.5	1.7	-9.6	-14.4	21.0	4.4	26.1	13.6
Month 6	-12.6	1.7	-9.6	-14.2	20.8	4.4	25.6	13.7

Table 5.4. Descriptive statistics for carbon and nitrogen isotopes from hair divided per months before death, for the Tarapacá Coast individuals.

Descriptive statistics for carbon and nitrogen isotopes in hair per month before death are presented in Tables 5.3 and 5.4 shows the values for Pica 8. Carbon and nitrogen isotope averages were very conservative varying only in 0.3‰ during the 6 months. The maximum values for $\delta^{13}C$ and $\delta^{15}N$ were registered for the fourth and fifth month before death, respectively. Coastal Tarapacá hair averages also vary in 0.3‰ for carbon isotopes. In contrast, nitrogen isotope averages show a difference of 0.9‰ during the 6 months. The fourth and fifth months registered the highest average values for $\delta^{13}C$, while the first month shows the highest $\delta^{15}N$ average value of the sample.

Comparisons were made for hair $\delta^{13}C$ and $\delta^{15}N$ by sex in Pica 8 and the coastal individuals. The latter were considered as one group. For Pica 8, no significant differences were found for carbon (Mann Whitney, W=120, $p>0.05$) or nitrogen isotopes (Mann Whitney, W=161, $p>0.05$). The same was observed for the Tarapacá Coast individuals (Mann Whitney, $\delta^{13}C$ W=4, $p >0.05$; $\delta^{15}N$ W=6, $p >0.05$).

When Pica 8 and the Tarapacá Coast individuals were compared significant differences were registered for both carbon (Mann Whitney, W=271, $p<0.05$) and nitrogen isotopes (Mann Whitney, W=2, $p<0.05$).



(a)

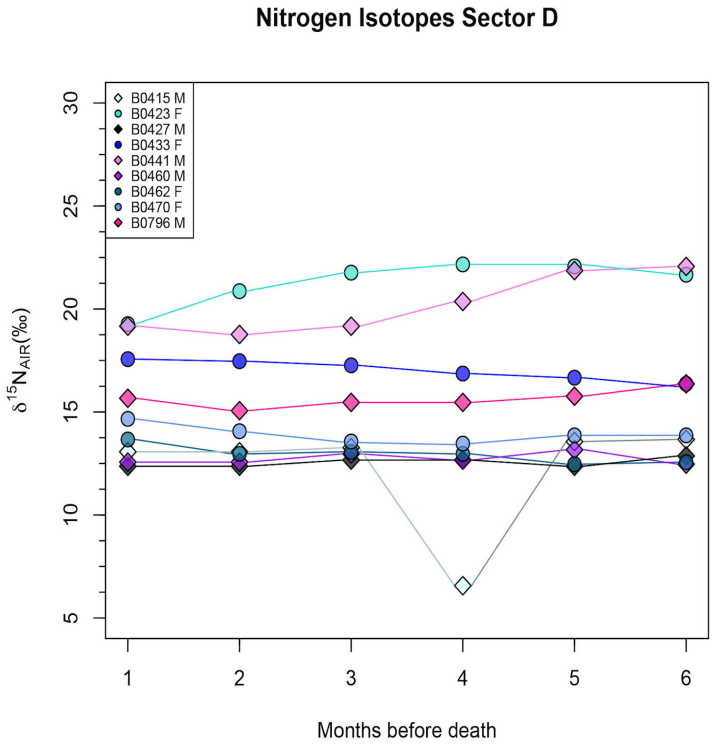
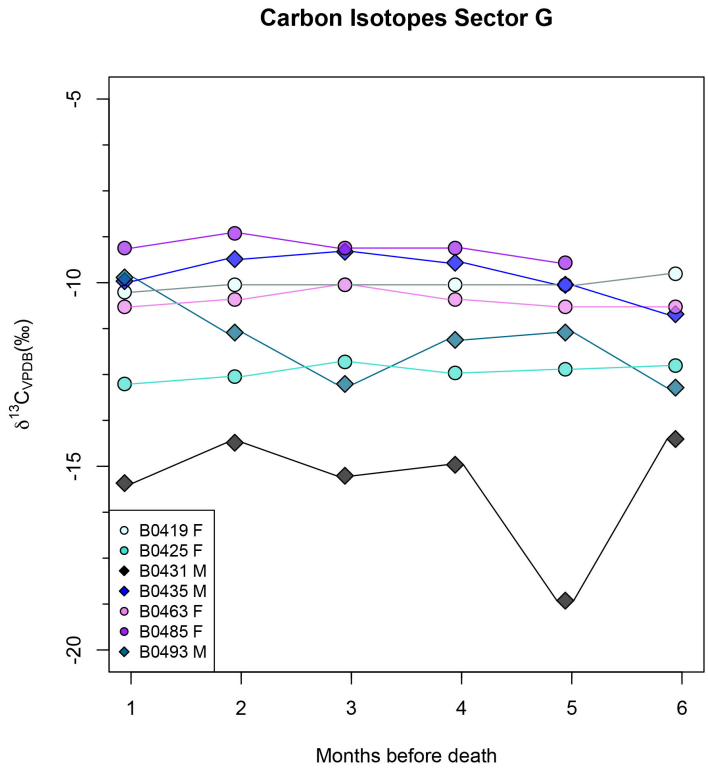
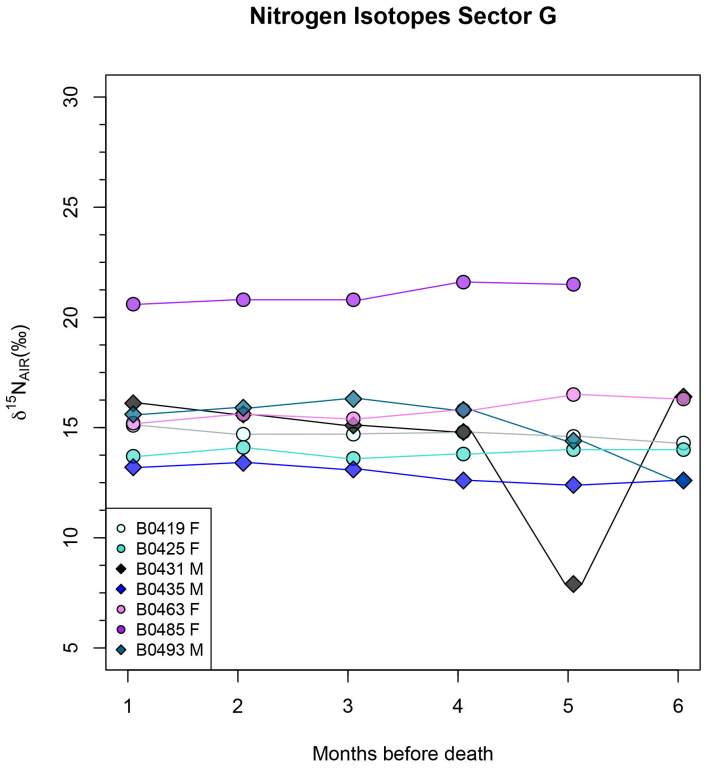


Figure 5.3. Plot for hair $\delta^{13}C$ (a) and $\delta^{15}N$ values (b) per months before death for Pica 8's Sector D.

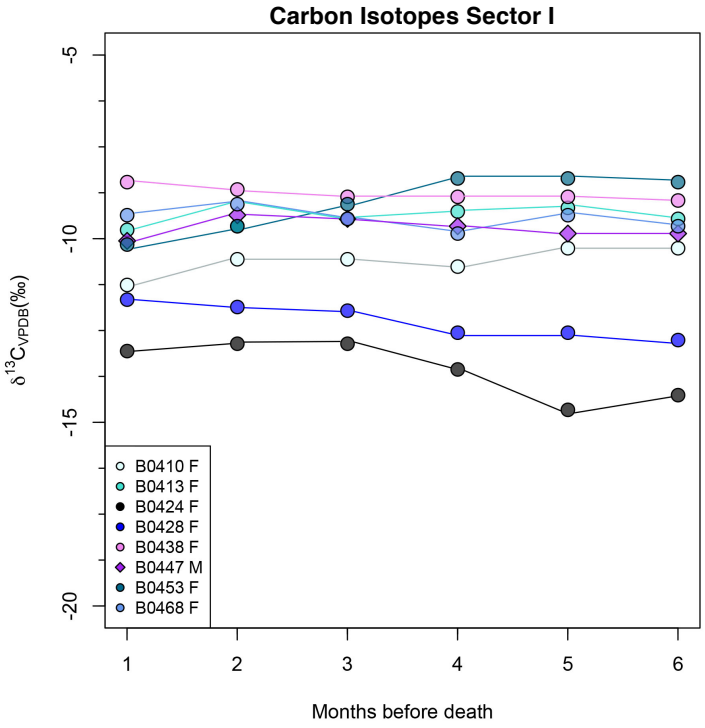


(a)

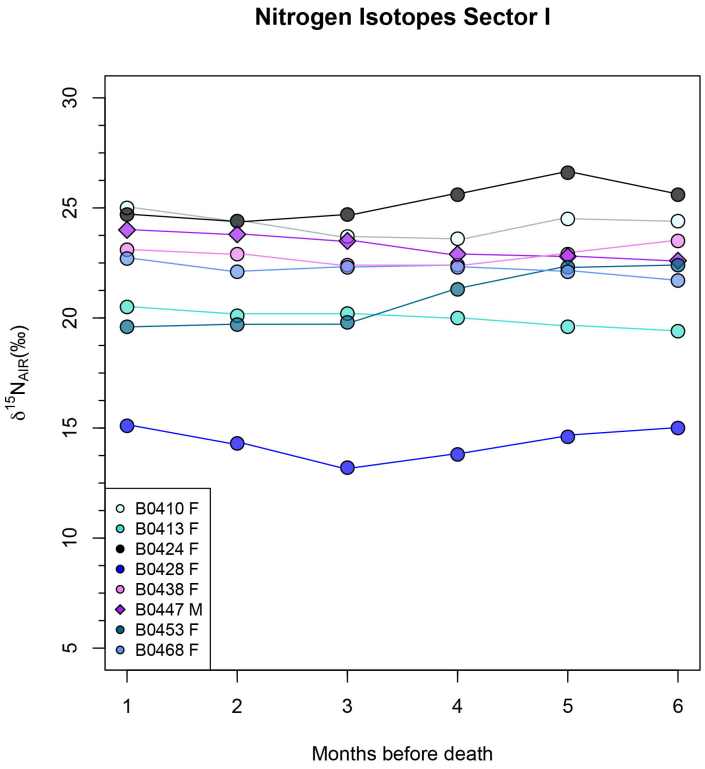


(b)

Figure 5.4. Plot for hair $\delta^{13}C$ (a) and $\delta^{15}N$ values (b) per months before death for Pica 8's Sector G

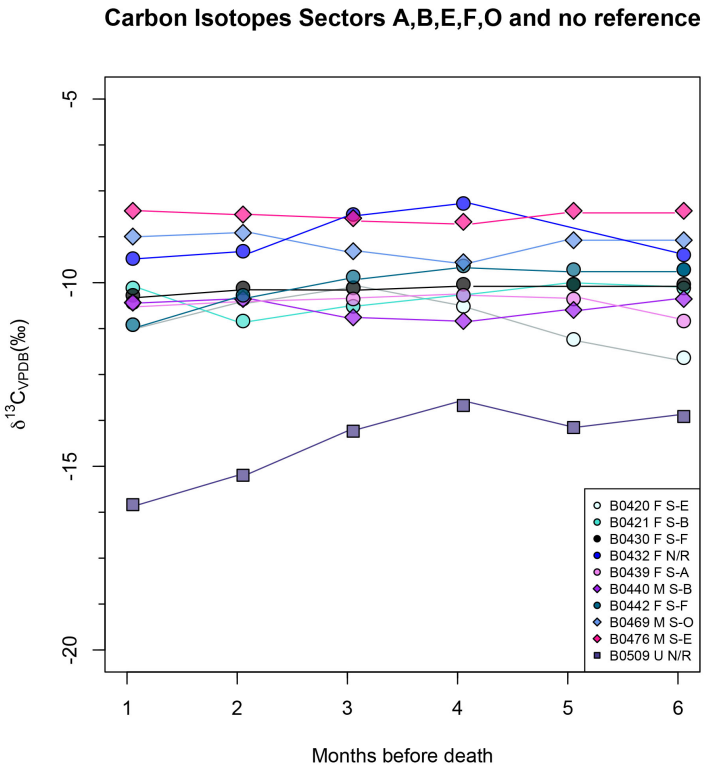


(a)

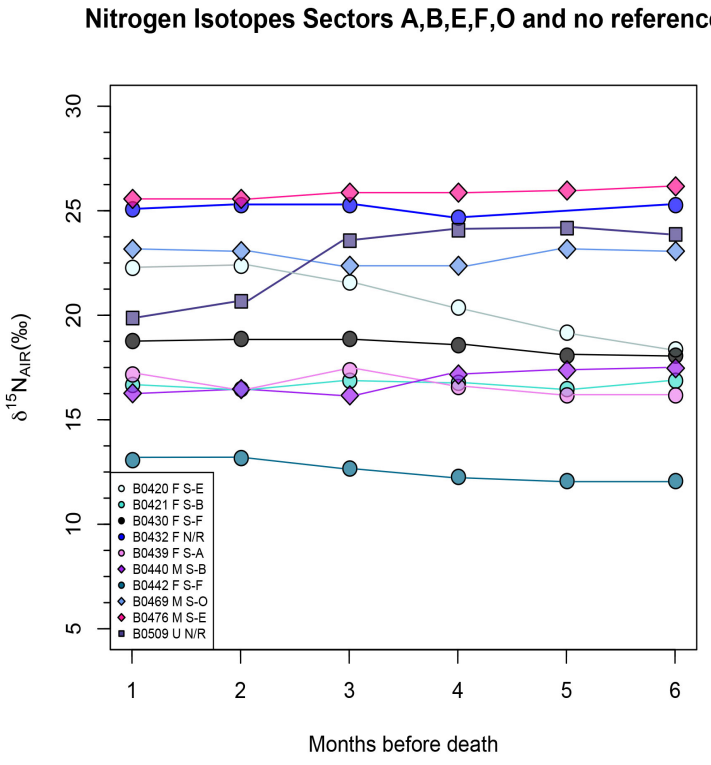


(b)

Figure 5.5. Plot for hair $\delta^{13}C$ (a) and $\delta^{15}N$ values (b) per months before death for Pica 8's Sector I

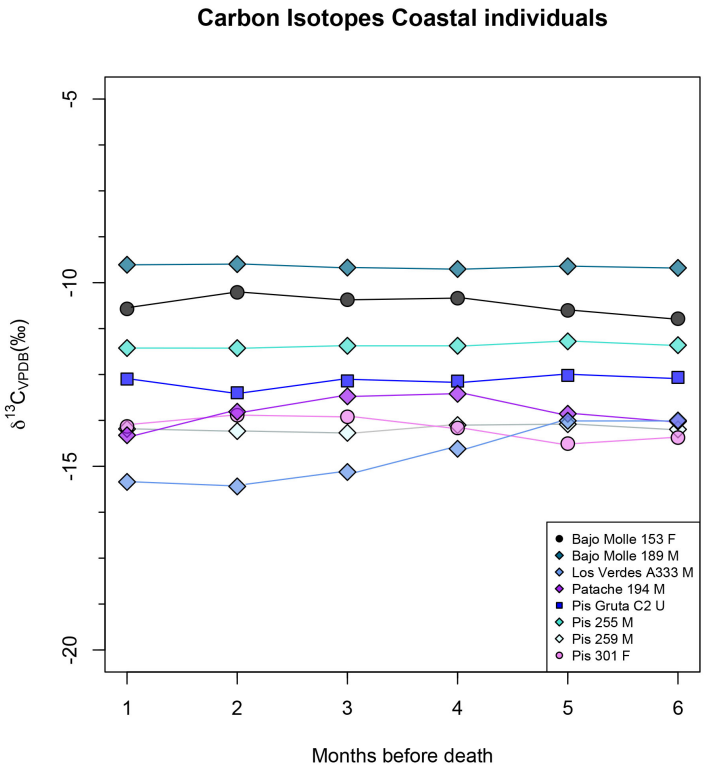


(a)

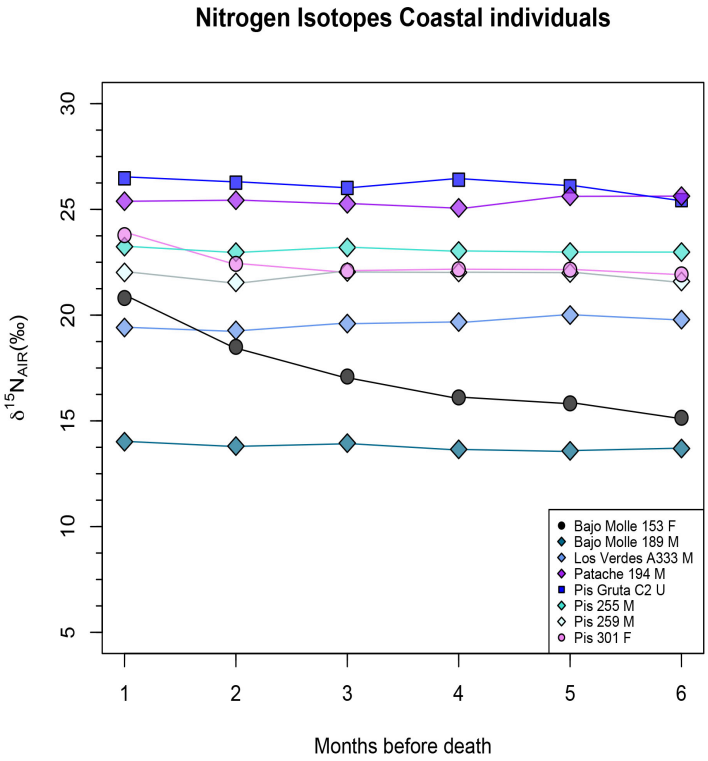


(b)

Figure 5.6. Plot for hair $\delta^{13}C$ (a) and $\delta^{15}N$ values (b) per months before death for Pica 8's Sectors A,B,E,F,O



(a)



(b)

Figure 5.7. Plot for hair $\delta^{13}C$ (a) and $\delta^{15}N$ values (b) per months before death for Tarapacá Coast individuals.

5.5 Dietary composition during the LIP

The results of this research were complemented by previous data obtained for bone collagen and apatite of the cemeteries Pica 8, Quitor 6 (Santana-Sagredo et al., 2015a) and Quillagua Cementerio Oriente (Santana-Sagredo et al, 2015b). All the values are plotted together in Figure 5.8a-b for bone collagen and apatite. There is a clear isotopic composition pattern associated with cultural affiliation. This aspect was previously observed for the Pica 8, Quitor 6 and Quillagua cemeteries (Santana-Sagredo et al., 2015a; 2015b).

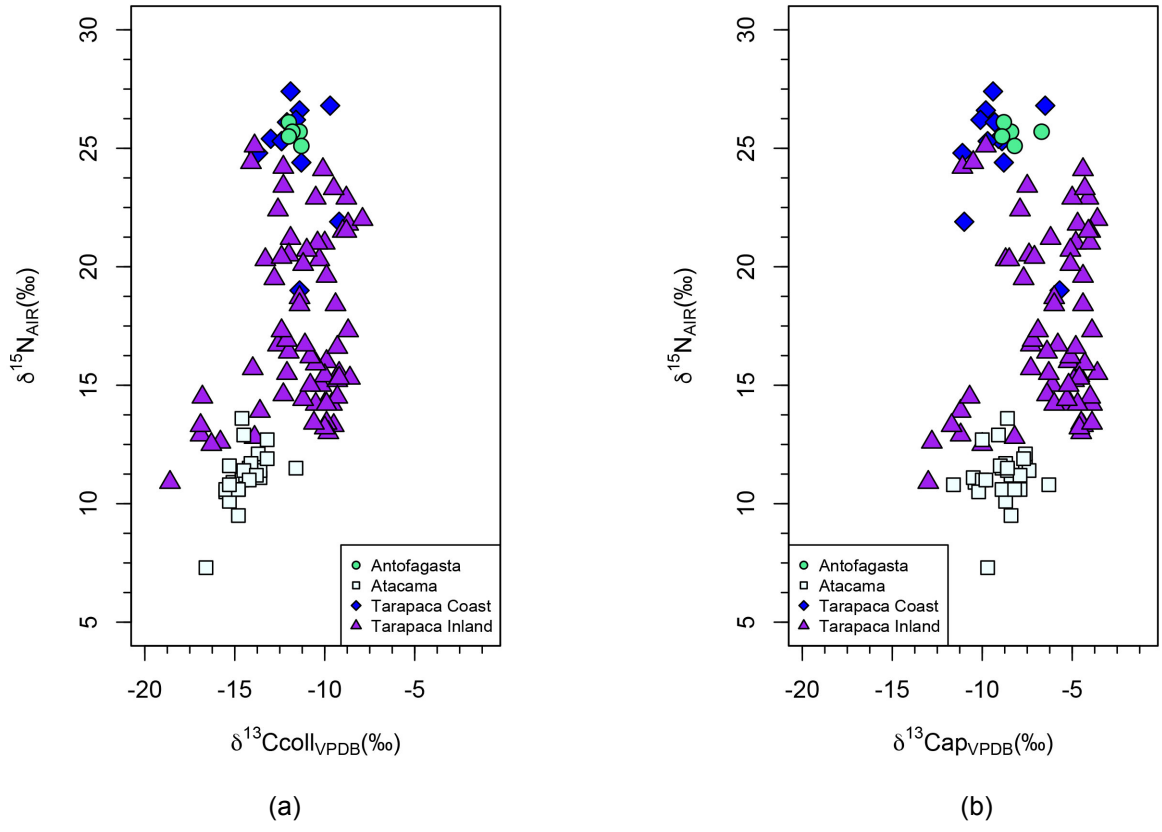


Figure 5.8. Bivariate plot for $\delta^{13}C$ and $\delta^{15}N$ values of bone collagen (a), and bone apatite (b) by cultural group. Here, previously isotopic data for the Quitor 6, Pica 8 (Santana et al., 2015a) and Cementerio Oriente (Santana et al., 2015b) were included.

As seen in the results section, the Antofagasta and Tarapacá Coast groups have high $\delta^{13}C$ and $\delta^{15}N$ values, indicating a marine diet tradition. The Tarapacá Inland group presents significant diversity within in their results for $\delta^{13}C$ and $\delta^{15}N$. In contrast, the Atacama-Alto Loa people had a very consistent and homogenous diet composition compared to Tarapacá. The four groups can be identified clearly by their cultural association and diet.

These results beg the question, what were they eating and why are the differences between these groups so marked? Human results were plotted together with the flora and fauna values (Figure 5.9) presented in chapter 4. Diet isotopic values were considered for the human groups, assuming a fractionation of +5‰ for carbon and +4‰ for nitrogen in bone collagen. Clearly the Antofagasta and Tarapacá groups fall closer to the marine resources and C_3 plants, especially crops and wild coastal forms. However, results for bone collagen and apatite suggest there was maize ingestion by some coastal individuals, especially for the Tarapacá Coast. These results are more enriched in ^{13}C than pure marine consumers, such as seals ($\delta^{13}C_{coll}$= -12‰; $\delta^{13}C_{ap}$= -8‰; Santana-Sagredo et al., 2015a) – reaching maxima of around -8‰ for collagen and -6‰ for apatite. However, maize consumption was not as high as in the inlands.

The Tarapacá Inland group plots closer to the values expected for consumption of C_4 crops, compared to the coastal groups and Atacama-Alto Loa. At the same time, it falls in between the terrestrial and marine resources, strongly suggesting a mixed diet. The Atacama-Alto Loa group, on the other hand, plots closer to terrestrial C_3 resources (wild fruits and crops). It is of great relevance to consider the possible impact of the $\delta^{15}N$ crop values on human diet. Since values reach figures above 20‰, they clearly could be contributing to the nitrogen isotopic composition of humans, especially in Tarapacá Inland. This last group falls particularly close to the C_4 crops, dominated by

maize. However, it is known that maize protein composition is very low – having 12.9% protein in grains and 13.7% in popcorn[1]. Further research is needed in order to understand how fertilised crops would affect the nitrogen isotopic composition of humans. This is of great relevance for avoiding confusion regarding the interpretation of possible marine input.

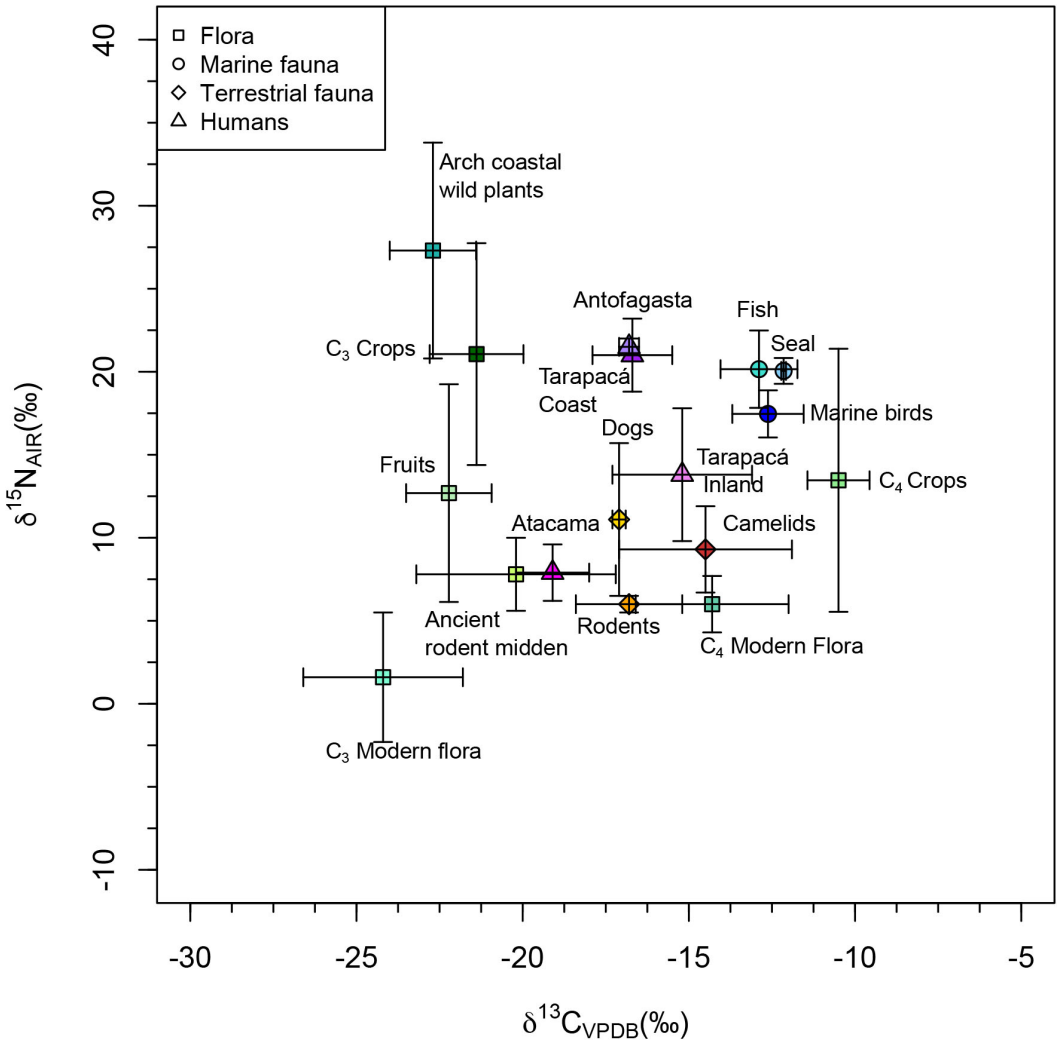


Figure 5.9. Bivariate plot for $\delta^{13}C$ and $\delta^{15}N$ values plotted for the cultural groups analysed here together with archaeological local resources values. Diet values were calculated for the human groups considering a fractionation factor of +5‰ for collagen and +4‰ for nitrogen. The ancient rodent midden values were obtained from Díaz (2014).

The dietary information provided by the isotopic analysis is in strong agreement with the archaeological evidence. As discussed in Chapter 3 and here, coastal contexts

[1] Information obtained from the Food and Argricultural Organization of the United Nations website, www.fao.org

show mainly marine food, including fish, mussels, octopus, marine birds and sea mammals along the Pacific Coast of northern Chile (Núñez, 1984; Moragas, 1995; Uribe, 2006; Ballester and Clarot, 2014). This evidence supports the continuity of a strong maritime tradition from very early times in the Atacama Desert throughout the LIP and later periods. Judging by their carbon apatite values, it is suggested that maize was not a fundamental component of coastal population diets. They probably did have access to maize (as suggested by the occurrence of this crop in coastal sites – Uribe, 2006) and consumed it but not in the same frequency and intensity as seen in inland Tarapacá. This could be explaining the significant differences for $\delta^{13}C_{ap}$ observed between the Tarapacá Coast and Inland groups. Statistical differences were also reported for these two groups regarding nitrogen isotopes. As mentioned before, Tarapacá Inland shows high variability in $\delta^{15}N$, ranging from 10‰ to 24‰. Many individuals were probably consuming a rather mixed terrestrial-marine diet resulting in values close to 15‰. The coastal influence in Inland Tarapacá is clear, following the considerable marine evidence found at inland sites such as Caserones and Pica 8 (Núñez, 1984; Uribe, 2006). However, the ingestion of fertilised crops cannot be discarded, as a cause of the elevated $\delta^{15}N$ values mentioned above. Seabird guano might have had an important influence on the $\delta^{15}N$ values, especially for the Tarapacá groups that show the highest results. In addition, it is clear that the Tarapacá Inland groups had the higher maize consumption of all the groups analysed here. The archaeological evidence, especially for Pica 8, also supports this aspect. Núñez (1984) describes the maize presence in the cemetery as “impressive”, with textile bags absolutely full of this C_4 crop.

The Atacama-Alto Loa group is significantly different to the other three groups, showing the lowest carbon and nitrogen isotope values. The Atacama-Alto Loa groups maintained terrestrial diet tradition, also documented from previous moments of the

local prehistory, such as the Middle Period (Núñez, 1995; Pestle et al., 2015, Uribe et al., 2016). Even though they had access to C_4 resources, maize was not an essential part of their diet, which instead exhibits a rather mixed C_3-C_4 signal. In contrast to the Tarapacá Inland groups, The Atacama-Alto Loa shows lower $\delta^{13}C_{ap}$ values, suggesting less maize consumption. Questions remain on the possible use of fertilisers, in particular of seabird guano, on the crops consumed by the Atacama-Alto Loa groups, since their $\delta^{15}N$ values are lower than the ones in Tarapacá. Nevertheless, llama dung could have been used in the Atacama Oases and Alto Loa as a fertiliser, leading to a lesser increase in the $\delta^{15}N$ values of crops. Llama dung, in contrast to seabird guano, would only increase the crop values between 2-4‰ (Szpak et al., 2012 a,b).

Tooth enamel presented quite interesting results for most of the groups. They show a general tendency to be more enriched in ^{13}C compared to bone apatite. However, this difference was only significant for the Tarapacá Coast values. This is remarkable since coastal individuals tend to present lower carbon apatite values. The data suggest a different type of diet consumed during childhood that was rich in C_4 resources. No evidence has been documented so far for childhood diet during the LIP. There is a paucity of ethnographic information on this topic. It is known that during Inka times children were specially prepared and fed for *capacocha* sacrifices in the Andes (Wilson et al., 2007). However the LIP societies were different to the Inka Empire, and so far no evidence of sacrifices in northern Chile has been documented. In addition, many of the teeth analysed here belong to adult individuals that possibly died of natural causes or disease but not sacrifice. Thus, it is suggested that children in had general diets in which maize featured more strongly than in adulthood. It is striking that this situation happened on the coast, after showing very low values for their carbon isotopes during adulthood. It is not clear either, how maize was consumed during infancy (e.g. as a drink, popcorn, grounded, etc).

When comparing the tooth enamel results by location, significant differences were found between the Atacama and Tarapacá Inland groups. As mentioned before, the ingestion of maize and possibly other C_4 resources such as *Amaranthus sp*. (Cadwallader, 2012) was considerable in Tarapacá. However, during childhood this was even higher – especially for Tarapacá reaching values above 0‰. This suggests that many of Tarapacá Inland children had a complete C_4 based diet.

Hair results for Pica Inland and Tarapacá Coast show a similar situation compared to that reported for bone collagen. On one hand Pica 8 results suggest a mixed terrestrial-marine diet, while Tarapacá Coast retain the marine tradition with high $\delta^{13}C$ and $\delta^{15}N$. The average results for $\delta^{13}C$ and $\delta^{15}N$ per month in both groups do not show strong changes through time. Outlier cases were reported in both groups and will be discussed in the following section.

Significant differences were found for carbon and nitrogen isotopes between Pica 8 and Coastal Tarapacá. The values for $\delta^{13}C$ in the coast are lower in contrast to the inlands probably due to low maize ingestion. Nitrogen isotopes results are higher in coastal individuals. Even though Pica 8 also shows individuals with high $\delta^{15}N$ values, the number of individuals with values close to 15‰ (or lower) is also important. This could be suggesting significant dietary differences with the coast.

Bone collagen and hair keratin were plotted together in Figure 5.10. Unfortunately, only one of the coast individuals had bone and hair tissues to be compared. Hair keratin values were adjusted to bone collagen equivalent values, assuming they are depleted in 1.4‰ for carbon isotopes and 0.86‰ in $\delta^{15}N$ relative to collagen (O'Connell et al., 2001). Figure 5.10 shows the same distribution pattern of nitrogen isotope values for

Pica 8. However, hair carbon isotope values are slightly lower compared to bone, especially for the group of individuals with figures around 15‰. The $\delta^{15}N$ values for bone and hair are almost the same. The changes are seen mainly for $\delta^{13}C$. This situation could be reflecting a lesser degree of maize consumption during the last 6 months before death of the individuals, probably due to harvest seasonality (Williams and Katzenberg 2012). Even though they had deposits of maize to consume along the year (Núñez, 1984), probably during harvest times maize consumption increased considerably. However the lower $\delta^{13}C$ results observed for hair keratin could be related to other cultural or physiological reasons that need further research.

As previously mentioned, the Pica 8 cemetery was arbitrarily divided into sectors (1984). The results presented in section 4.3 for hair keratin were organised by sector showing interesting groupings (Figures 5.3a-b, 5.4a-b, 5.5a-b, 5.6a-b, and 5.7a-b). Sectors D and G contain mainly individuals with $\delta^{15}N$ results around 15‰, whereas sector I has individuals with values above 20‰. All the bone collagen results obtained here together with those previously published (Santana-Sagredo et al., 2015a) are plotted in Figure 5.11a, together with the hair keratine values (11b) by sector. As seen in Figure 5.5b, the highest $\delta^{15}N$ results are from sector I. Only one individual has a lower value, but this appears only in the hair keratine isotopes. Sectors D and G show a wider distribution of $\delta^{15}N$ values, having individuals more and less enriched in ^{15}N. Significant differences were reported but only for bone collagen. Sectors G and I as well as D and I differ statistically for $\delta^{15}N$ (Kruskal Wallis, chi-square= 17.65, $p<0.05$; ANOVA, F-value=4.77, $p<0.05$).

Burial offerings in Sector I show the higher concentration of evidence associated with the coast, including dry fish, fish bones, marine bird feathers, shells (Núñez, 1984) and even dry octopus (Núñez, 2013 pers. comm.). At the same time, historic documents

dating to AD 1660 refer to a group of fishermen living in Pica (Rostworowski, 1986). The evidence suggests that individuals buried from sector I could have a direct association with the coast.

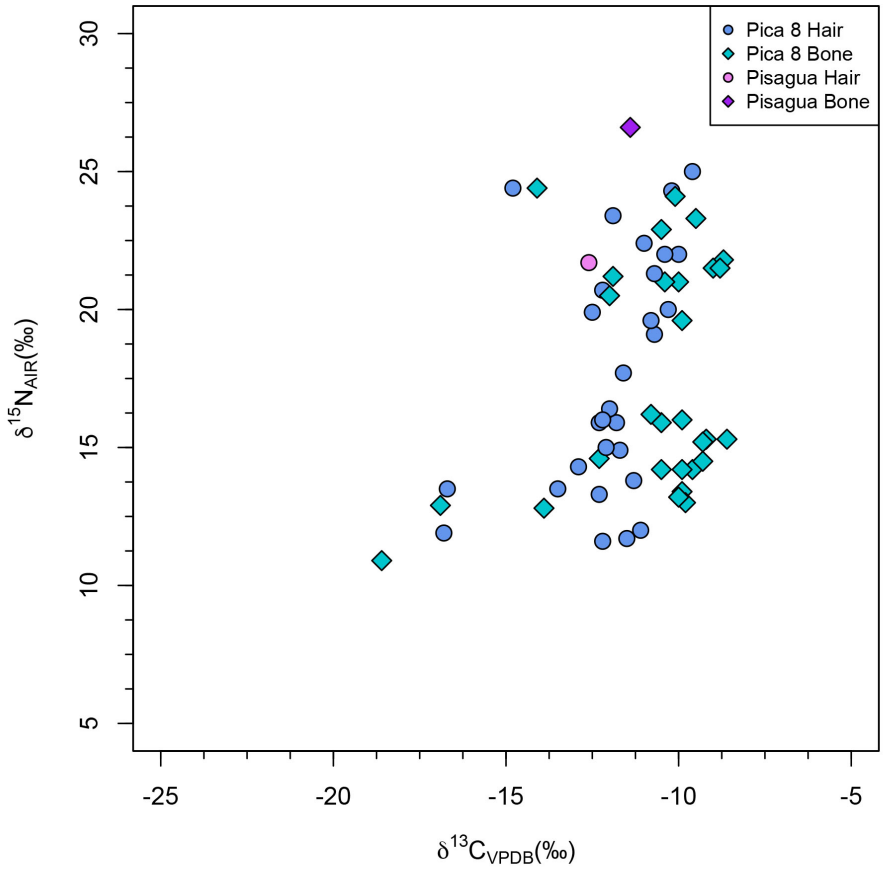


Figure 5.10. Bivariate plot for $\delta^{13}C$ and $\delta^{15}N$ values of hair and bone collagen from the Pica 8 and Pisagua sites. Hair values were corrected to bone collagen values considering +1.4‰ for carbon and +0.8‰ for nitrogen (O'Connell et al., 2001).

Sector G, on the other hand, was previously associated with *altiplano* colonies by Núñez (1984). As based on the finding of textile styles that looked similar to those from the Titicaca area. However, Agüero (2006) argues that the textiles found in Sector G show a very local Pica-Tarapacá style. The diet reconstruction carried out here, together with previous results for this sector (Santana-Sagredo et al., 2015a) also

suggests a predominantly local diet. For instance, their values are not completely terrestrial as are those observed for the Atacama-Alto groups, ingesting some fish.

The causes behind the differences between these sectors are still unknown. It is not clear if they could be related to temporal aspects or rather synchronic factors such as identity and ethnicity roles. This topic will be further explored in Chapter 6.

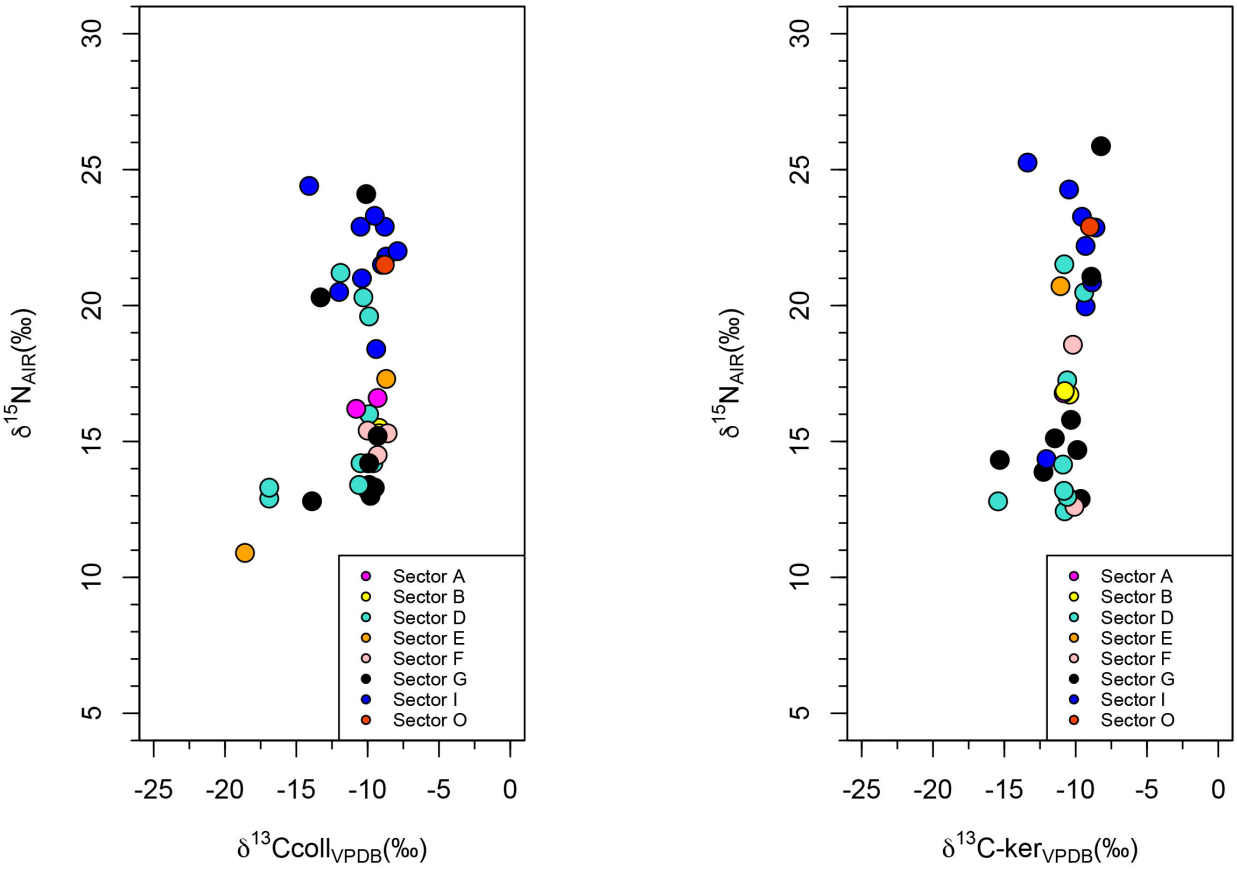


Figure 5.11. Bivariate plot for $\delta^{13}C$ and $\delta^{15}N$ values for (a) bone collagen and (b) hair keratin by sector for the Pica 8 cemetery.

5.6 The enigmatic cases: Non-local and change diets in Atacama and Tarapacá

The previous sections discussed the main dietary characteristics of the Antofagasta, Atacama-Alto Loa and Tarapacá cultural groups. For each of them a local dietary pattern was described. However, in three of these groups outlier individuals were identified. They show different isotopic compositions compared to the local groups of Atacama-Alto Loa and Tarapacá Coast and Inland. Some of them also present marked changes in their diets through life. No outliers were reported for Antofagasta. By combining the new data obtained here with the previous published research in Quitor 6, Pica 8 (Santana-Sagredo et al., 2015a) and Quillagua-Cementerio Oriente (Santana-Sagredo et al. 2015b), it was possible to spot the outlier individuals and better understand their dietary changes. However, the data of this research alone, also gave information on non-local diets.

The Atacama cultural group presents two particular cases from the Quitor 6 cemetery. One of them is burial T45, a female individual that has the lowest $\delta^{15}N$ value in the cemetery (9.5‰). This female is the only individual having non-local objects associated with her burial offerings. Foreign pottery coming from southern Bolivia (Lípez region) was found next to her skeleton (Costa Junqueira, 1988; Uribe 2016, pers. comm.). However, her carbon isotopes for tooth enamel and bone apatite look 'local', being quite similar to the rest of Quitor 6.

On the other hand, the female burial T54 shows a particularly high $\delta^{13}C$ for her tooth (second upper molar) enamel (-2.1‰). This is the only person in Quitor 6 suggesting a heavy reliance on maize, contrasting dramatically with the rest of the individuals. Nevertheless, she was buried with local Atacama pottery (Costa-Junqueira, 1988). Yet, along with another case, these are the only individuals at Quitor 6 showing evidence of

hooks for attaching transport bags on camelids. These objects might suggest activities related to mobility and camelid caravans.

For the Tarapacá Coast, individuals Pis 302 and Pis-5-34 from Pisagua, were only analysed for enamel apatite. However, they show very high and low $\delta^{13}C$ results, respectively. Individual Pis 302 has a $\delta^{13}C$ value of -12.9‰, quite low for a coastal individual, when compared to the enamel apatite results for the Antofagasta and Tarapacá Coast (with values usually close to -10‰ and -9‰, see Table 3). These data suggest a predominantly C_3 terrestrial diet with no ingestion of maize, looking rather like an "*altiplano*" diet. This contrasts with the general tendency of enamel apatite to show higher $\delta^{13}C$. On the other hand, individual Pis-5-34 presents the opposite situation with a value of -3‰. This value is particularly high for what was reported for coastal individuals (Table 3), suggesting a heavy reliance on maize.

Table 5.5 shows all the outlier cases with more than one type of tissue analysed. Information for carbon and nitrogen isotopes for each tissue analysed (when available) is reported. In addition, relevant information regarding the burial offerings has been included in Table 5.5. Two more outlier individuals are presented for the Tarapacá Coast group. One case is from Bajo Molle 1 while the other comes from the rescue carried out in Bajo Molle Edificio Armada. Individual BM1-153 (Female) presents a dramatic change in her hair isotope composition (Figure 5.7a-b). An increase of approximately 5‰ occurred during her last 6 months of life, moving from 15.1‰ to 20‰. During month 6 before death, her isotopic signature/diet resembled that of the Tarapacá Inland group. However, by the 4th month before death her isotopic composition changed to become more similar to the coastal pattern (Figure 5.7a-b). However, the Tarapacá Inland group also has individuals with values above 20‰.

Nevertheless, it is striking that this woman was buried in a coastal cemetery, and that her diet changed so dramatically during her last months of life.

Individual BM Ed. Arm. 189 shows a high $\delta^{13}C$ value for its enamel apatite, assimilating the one of Pis-5-34, and suggesting an important maize consumption. Even though this individual was buried in Bajo Molle, the diet did not change during its last 6 months of life. In fact, the individual kept the values around -9.5‰ and 14‰ for carbon and nitrogen, respectively, being very similar to the Tarapacá Inland group. Two possible explanations are considered: one is that this was an inland individual that died by the coast; or, alternatively, that this was an inland person living by the coast but retaining the diet of its origin place in the interior. Unfortunately, no information about its burial offerings was available. However, it had a piece of textile attached to its hair (Figure 5.12) that could be associated with a Tarapacá style.



Figure 5.12. Individual BM Ed Arm. 189. A piece of textile is attached to his hair.

Núñez (1984), Sanhueza (1982) and Moragas (1995) suggested that the Tarapacá Coast, including the Bajo Molle cemeteries in particular were part of inland colonies

probably controlled by the Pica oases. However, as inferred from the isotopic evidence, there was probably a strong marine tradition in their dietary patterns. Together with the archaeological evidence for the LIP, this study does not support the colony hypothesis. There is a clear presence of the inland individuals by the coast but again it does not necessarily mean the imposition of colonies in that region (Adán et al. 2004).

Pica 8 individuals from the Tarapacá Inland group show a diverse range of outlier individuals, with some of them eating very terrestrial-C_3 diets, while others were consuming marine diets with no C_4 resources. Individuals with bone and hair tissues were compared and plotted together in Figure (5.13).

One of the most remarkable cases is individual B0420 (Female). Her carbon values for tooth enamel, bone apatite and bone collagen as well her nitrogen collagen composition strongly suggest a terrestrial-C_3 based diet. This individual shows the lowest $\delta^{15}N$ (10.9‰) value of the entire Pica 8 sample – being even lower than the Atacama-Alto Loa group average (11.9‰). However, a considerable change occurred during her last months of life (Figure 5.13), increasing her carbon and nitrogen isotope values dramatically up to -11‰ and 22‰, respectively. There was probably a switch to a marine diet, an ingestion of fertilised C_4 crops, or both. Individual B0420 was buried with a non-local bag for transporting objects or *talega* (carried by camelids as beasts of burden), but also local Pica pottery (Zlatar, 1984). The bag style has been observed in the Atacama oases but it could also be associated with the *altiplano* (Agüero, 2016 Pers. comm.). This could be providing insight into mobility and camelid caravans. Another striking aspect of this individual is the presence of a slingshot in her burial, and bone trauma evidence in her hips and clavicle (Retamal, 2016 Pers.comm.) The trauma in the pelvis bone does not show a complete recovery so probably it happened relatively close to her death. In this sense, this individual probably arrived from a foreign location, changing her diet in the Pica oases during her last months of life.

Individual B0453 followed a similar pattern to the one just presented for B0420, showing very low in $\delta^{13}C$ results for her tooth enamel. However, the difference between them is that individual B0453 changed her diet during her last years of life. An increment in her carbon values is reported for carbon isotopes of bone and hair. Her $\delta^{15}N$ values suggest an ingestion of marine diet, fertilised crops or both.

In contrast to individuals B0420 and B0453, individual B0427 (male) shows low values for its carbon and nitrogen isotope composition during his entire life. Even though he was buried in Pica 8, he simply did not change his diet. In addition, this individual's burial offerings show mainly objects associated with either hunting or defensive/war activities. No textiles or pottery was found in this burial (Zlatar, 1984).

Similar but at the same time opposite to individual B0427, individual B0447 (male) does not show changes in his diet through life either (Figure 5.13). However, his diet composition was absolutely different to the one of B0427, showing high $\delta^{13}C$ and $\delta^{15}N$ values for tooth enamel, bone collage and apatite, and hair. His isotopic evidence suggests a diet based in maize and marine resources. This individual has by far one of the most numerous and heterogeneous burial offerings of the cemetery (Zlatar, 1984). The pottery objects found in his burial are associated with the local Pica styles but also with the *altiplano* and Atacama-Alto Loa culture (Table 5.5). In addition, objects associated with hunting/defensive activities were found, including 16 arrows, with some of them decorated and no evidence of use.

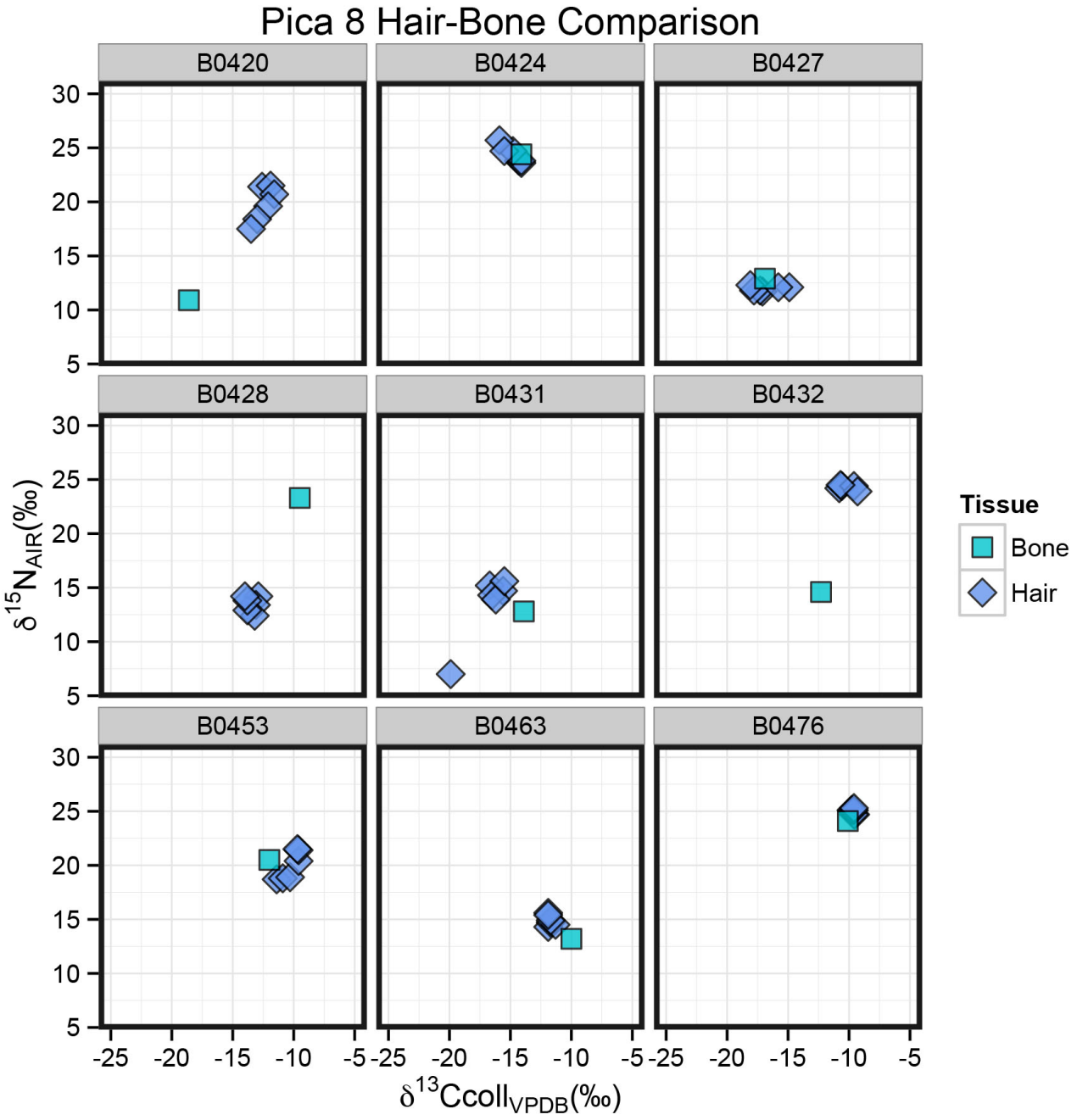


Figure 5.13. Bivariate plot for $\delta^{13}C$ and $\delta^{15}N$ values of hair and bone collagen from outlier individuals of Pica 8. Hair values were corrected to bone collagen values considering +1.4‰ for carbon and +0.8‰ for nitrogen (O'Connell et al., 2001).

Individual B0424 (male) follows a similar pattern as B0427 and B0447 by not showing significant changes in his diet along his life. However, this is the only individual in Pica 8 whose values could be strongly associated with a marine diet and absence of C_4 crop consumption. His carbon apatite values for tooth enamel and bone apatite are not

sufficiently enriched in ^{13}C to (Table 5.5) support maize ingestion. This contrasts with the previous B0447 case, for which carbon isotope values from enamel and bone apatite were quite high.

Individuals B0428 and B0432 show an interesting situation. The former has high values in $\delta^{13}C$ and $\delta^{15}N$ during its infancy and adulthood (last years of life), with nitrogen isotope results above 20‰. However, hair keratin values suffered a drop in both $\delta^{13}C$ and $\delta^{15}N$, decreasing to 15‰ in the latter. The opposite situation occurred for individual B0432, in which hair values increased in 5‰ for $\delta^{15}N$ compared to bone collagen. Individual B0428 was buried with a *talega* (bag for carrying objects) that shows evident marks of use. The *talega* is even broken because of its intense use. Again, this type of textile could be giving insights on the mobility patterns of these individuals.

Finally individual B0476 (male) had a diet heavily relied on maize and marine resources during its entire life. It is noticeable that his carbon isotopes from tooth enamel and bone apatite are strikingly similar (around -4‰). This contrasts with other Pica 8 individuals (except for B0427) that show a change in their enamel and bone apatite values. This suggests individual B0476 did not change its diet from childhood to adulthood. Local Pica Chiza pottery was present in his burial offerings. However, a tropical bird (*Ara ararauna*) probably from the Amazon was also associated with the offerings.

For the Cementerio Oriente in Quillagua, two outlier individuals could be identified. Both (CTX Fun 2 and 3) show very low ^{13}C results for tooth enamel. However, during their 10 last years of life, they changed their diet composition consuming more C_4 resources (probably manured) with marine resources. This dietary pattern (during adulthood) accords quite well with that observed for the other individuals buried in

Quillagua (Santana-Sagredo et al., 2015b). The burial offerings present a mix of Atacama and Tarapacá cultural objects between textiles and pottery (Agüero et al., 1999).

5.7 Colonial diets? *Caravanero* diets? Local diets?

The results obtained for the different cultural groups here clearly show local dietary patterns. It is known from the archaeological evidence that *altiplano* people based their diets on terrestrial resources, predominately the consumption of camelids and small mammals (Núñez, 1984; Schiappacasse et al., 1989). At such high altitudes maize agriculture is quite difficult, hence the consumption of *altiplano* crops such as potatoes and *quinoa* is more likely. No isotopic evidence for a typical *altiplano* diet was observed in any of the cultural groups analysed here. In this sense, the Murra hypothesis (1972) about *altiplano* colonies in the lowlands including valleys and coast for the LIP in northern Chile (Schiappacasse et al., 1989) can be rejected from an isotopic/dietary perspective. As well as with showing very local dietary patterns, the archaeological evidence for each of these groups strongly suggests local traditions. For instance, the Pica-Tarapacá styles prevail in the inlands and coast, reflected in the pottery and textiles types (Agüero et al., 1997; Agüero, 2006; Uribe, 2006). A similar situation is observed for the Atacama-Alto Loa Cultural group (Uribe et al., 2004). Thus, the foreign objects as well as the non-local diets are then understood as particular cases, outliers inside the local traditions.

The Atacama cultural groups (including the Alto Loa) are known by having closer contacts with the *altiplano* (Uribe et al., 2004). However, these contacts did not affect their local food traditions, keeping their terrestrial fauna consumption together with a mixed C_3-C_4 diet. This diet included maize, squash, probably beans and the *algarrobo* and *chañar* fruits. The same situation is observed for the coast of Antofagasta and

Tarapacá where the local maritime traditions prevailed through time. Inland Tarapacá, on the other hand, shows clear connections between the coast and valleys, with a mixed terrestrial-marine diet, including maize consumption.

The presence of people with different dietary patterns is clear in the Atacama, Tarapacá Coast and Inland groups. But the question is who were they? And why did they have different diets? The gyratory mobility theory proposes that small groups of caravan people constantly travelled through different locations in order to exchange objects and goods. If these people were in constant movement they probably changed their diets considerably from one place to the other. This could be reflected in the hair isotopes analysed here, since this information tells about the last 6 months of life. In this sense, it would be expected to see a clear "*caravanero*" dietary pattern for the outlier individuals. However, and surprisingly no "patterns" were observed for the outliers. In fact, each of the individuals with non-local diets is different from the other. This variability is observed as an intra and inter group characteristic. There is not a "type" of non-local individual with a specific diet. For instance, Pica 8 shows outlier individuals that did not change their diets at all during their lives (such as B0427 and B0424) while others had drastic fluctuations (such as B0420 and B0453).

More remarkable is the fact that no differences were observed by gender in any of the sites, contrasting with the Middle Period in which gender differences have been reported (Uribe et al., 2016). Clearly, gender was not playing a role in terms of dietary patterns nor mobility. Men and women are being buried with objects associated to caravan activities (such as the hooks and *talegas*). This contrasts with the modern ethnographic information for caravans in the Andes, in which only men are moving (Pimentel, 2012).

Both sexes appear to have had access to all type of resources, and both were moving around the Atacama Desert. Hence, it is suggested that not only the concept of *caravaneros* (Spanish masculine noun for caravan men) should be used for describing mobility in the past but instead *caravaneros* and *caravaneras* (Spanish female noun for caravan women). The presence of outlier men and women in these sites also calls for a consideration of the possible move of women from one group to the other in order to create new kin relationships (e.g. marriage). Again, not only women are moving but also men. This could be telling about both sexes (and not only women) travelling in order to establish new kin relationships.

The results obtained here also suggest people changed their diets at different times in their lives, from childhood to adulthood or only during their last months of life. No consistent patterns are observed in this regard.

New question rises on how these people moved and why did they do it. It is proposed here that mobility patterns were more complex than small caravan groups crossing the desert in order to exchange goods. Contrasting the archaeological and isotopic evidence becomes a necessary step in order to understand mobility. Here, the evidence warns about the simplistic assumptions of considering an individual as foreign, or a whole cemetery sector as a colony just because of non-local offerings in the grave. The outlier individuals of Pica 8 present a diverse set of burial offerings with local and non-local objects. For instance, individual B0420 had a clearly non-local diet during her childhood and adulthood, but moving to a local pattern during her last months of life. Even though she was clearly different, she was buried with local Pica pottery. In addition, Sector G of the cemetery was assumed to be an *altiplano* colony, as previously discussed. However, most of the individuals buried here show a clear local isotopic/dietary pattern as well as Pica-Tarapacá pottery and textiles types.

5.8.Conclusions

Isotopic analyses were carried out on different human tissues of the Antofagasta, Atacama and Tarapacá cultural groups. They showed local dietary patterns for each of these groups, which are in general agreement with the archaeological evidence. Local diet traditions prevail for northern Chile during the LIP, together with their cultural objects such as textiles and pottery types. However, non-local diets and important isotopic/diet changes were detected in most of the cultural groups. These individuals indicate a complex system of mobility in the Atacama Desert, in which some adapted and moved to the local diet traditions, while other retained the diets of their origin communities. This situation included men and women and it happened during different intervals of the individual's lives.

Further research is needed in order to understand the diet changes and mobility patterns during the LIP. The results caution about more complex situation that cannot be explained following the classic mobility theories. Oxygen stable isotopes as well as radiogenic strontium isotopes will be furthered discussed in the following chapter in order to evaluate human mobility during the LIP.

Cultural Group	Site	Ind.	Sex	$\delta^{13}C$ Tooth enamel	$\delta^{13}C$ Bone apatite	$\delta^{13}C$ Bone coll	$\delta^{15}N$ Bone coll	$\delta^{13}C$ Hair Ker 6th month	$\delta^{13}C$ Hair Ker 6th month	$\delta^{13}C$ Hair Ker 1th month	$\delta^{13}C$ Hair Ker 1th month	Burial offerings
Atacama	Quitor 6	T 45	U	-	-8.4*	-14.8*	9.5*	-	-	-	-	Foreign pottery probably from southern Bolivia-Lípez region; silver ring; spine cactus needles; necklace; camelid foot; hafts.
Atacama	Quitor 6	T 54	F	-2.1	-6.3	-15.3*	10.8*	-	-	-	-	Hooks for attaching bags on camelids; cupper mineral; squash object; local pottery; little wooden box.
Tarapacá Coast	Bajo Molle 1	153	F	-7.9	-	-	-	-11.0	15.1	-10.7	20.8	No information.
Tarapacá Coast	Bajo Molle Ed. Ar.	189	M	-3.3	-	-	-	-9.6	13.7	-9.5	14.0	Red-green textile tied to its hair. Pica-Tarapacá style (?).
Tarapacá Inland	Pica 8	B0420 S-E	F	-11.4	-13.0*	-18.6*	10.9*	-12.1	18.4	-11.2	22.3	Slingshot; Bag for transport *(talega)* with non-local style; attached set of cactus spines; Pica Gris Alisado pottery.
Tarapacá Inland	Pica 8	B0424 S-I	M	-8.5	-10.5*	-14.1*	24.4*	-14.1	25.6	-12.9	24.7	No information.
Tarapacá Inland	Pica 8	B0427 S-D	M	-11.5	-11.2*	-16.9*	12.9*	-16.7	13.1	-15.7	12.6	*Boleadoras* (weapon consisting of three ball-shaped stones attached to a rope with leather strings, used for animal hunting); cupper bracelet; *Carcaj* (quiver) with arrows and hafts.
Tarapacá Inland	Pica 8	B0428 S-I	F	-2.1	-4.3*	-9.5*	23.3*	-12.6	15	-11.5	15.0	Textile bag for transport (*talega*) broken and with evidence of intense use; pottery; little box for making sounds (little stones found inside); flute; “cowbell”
Tarapacá Inland	Pica 8	B0432 N/R	F	-4.0	-6.4*	-12.3*	14.6*	-9.3	25.3	-9.4	25.1	No information.
Tarapacá Inland	Pica 8	B0447 S-I	M	-1.9	-4.0*	-10.4*	21.0*	-9.7	22.6	-9.9	24.0	16 arrows; 2 *carcaj* (quiver); a slingshot; textiles including ceremonial bags

												(*chuspa*) and normal bags; loincloth; Hooks for attaching bags on camelids; Pica Chiza(1) and Pica Charcollo(1) pottery, *Altiplano* style pottery (3); Atacama-Aiquina(1) and Dupont(1) pottery style; wooden spoon; cactus spine; 1 rodent; leather sandals; among many other objects
Tarapacá Inland	Pica 8	B0453 S-I	F	-11.1	-7.4*	-12.0*	20.5*	-8.3	22.4	-10.0	19.6	No information.
Tarapacá Inland	Pica 8	B0476 S-E	M	-4.8	-4.4	-10.1	24.1	-8.1	26.2	-8.1	25.6	Textile ceremonial bags (*chuspas*); textile shirt; textile bag for transport (*talega*); baskets; Pica Chiza pottery; panpipes; leather sandals; tropical bird (*Ara ararauna*); Squash objects.
Tarapacá Inland	Cem. Oriente Quill.	CTX. Fun. 2	M	-11.3	-6.0*	-11.4*	18.7*	-	-	-	-	Atacama and Tarapacá style textiles including shirts and ceremonial bags (*chuspas*).
Tarapacá Inland	Cem. Oriente Quill.	CTX. Fun. 3	F	-11.9	-7.2*	-12.1*	16.9*	-	-	-	-	Atacama and Tarapacá style textiles including shirts and ceremonial bags (*chuspas*). Pica Charcollo-style pottery.

Table 5.5. Detailed isotopic and burial-offering information of outlier individuals by cultural group. Values obtained in previous research (Santana et al., 2015a,b) are marked with an asterisk (*). Burial offering information was obtained from Costa-Junqueira (1988) for Quitor 6, Zlatar (1984) for Pica 8 and Agüero et al. (1999) for Quillagua. Sector information was included for the Pica 8 individuals below their inventory numbers.

Chapter 6

Paired radiocarbon dating on human samples and camelid textiles from the Pica 8 Cemetery

The cemetery of Pica 8 was characterized in chapter 5 by having diverse isotopic, and hence dietary, patterns. The $\delta^{13}C$ values range from -18‰ to -8‰, and $\delta^{15}N$ values from 10‰ up to 24.4‰. Two possible explanations can be put forward to explain the observed variability: the first relates to temporal dietary change; and the second to socio-cultural divisions such as status, identity and ethnicity. Aiming to evaluate the first alternative, radiocarbon dating was carried out on 23 samples of Pica 8. By doing this analysis, it will be possible to evaluate whether or not the high isotopic variability is related to changes over time (which of course in turn would need to be explained). Considering their high $\delta^{15}N$ results, it seemed probable that many of the Pica 8 individuals consumed significant amounts of marine foods, so that the Marine Reservoir Effect (MRE) might be expected to affect the dates. For this reason, it was necessary to perform radiocarbon dating on paired human and terrestrial samples from the same graves. Camelid textile samples were chosen, since they are terrestrial herbivores and should not be affected by the MRE. This chapter presents the results obtained for the 23 radiocarbon dates, including nine paired bone collagen-textiles and five single dates, discussing the implications for diets at Pica 8. At the same time, new discussion emerges related to the MRE in the region and its impact on the dates. The interpretation on high $\delta^{15}N$ values is also discussed, evaluating different causes for the enrichment besides marine diets

6.1 Dietary diversity in the Pica 8 cemetery

The variability observed in the isotope composition of Pica 8 can be related to the sectors in which the cemetery was excavated: Sector I contains mainly individuals with very high $\delta^{15}N$, while most individuals in Sectors A and G exhibit lower values (Figure 6.1). Other sectors, such as D, are more variable, containing individuals with both high and low $\delta^{15}N$ values. While the cemetery can be confidently placed in the LIP, this period spans some 500 years, and it is possible that the observed isotopic variability is related to changing subsistence practices over time, whether through increased contacts with the coast (some 90 km distant, but clearly attested by finds of marine fish and shellfish, as well as by the stable isotope data), or through more intensive manuring of staple crops (suggested by experimental studies done on modern crops with seabird guano – Szpak et al., 2012a,b). The alternative is that the community at Pica 8 was comprised of a cosmopolitan mix of groups of people with different origins and diets, many of whom maintained their distinct cuisines. Resolving the question of whether the isotopic differences are diachronic or synchronic will greatly improve our understanding of the Tarapacá culture, and could (if the synchronic view is supported) provide new avenues of research into the conditions under which such 'sustained multiculturalism' arose, and how it was maintained.

Central to choosing between the two alternatives set out above is a robust chronology. What prevents this from being a straightforward task is the complication of the inferred high marine contribution to the diets of those individuals with extremely elevated $\delta^{15}N$ values, above 18‰ (Santana-Sagredo et al. 2015a). Apatite and collagen $\delta^{13}C$ measurements appear to support the importance of marine foods for these individuals, and a more terrestrially based diet for others. Moreover, the marine reservoir effect (MRE) is known to be extremely complex off the west coast of South America, being

heavily influenced by changing ocean currents, such as ENSO, and by deep-water upwelling, the intensity of which varies spatially and temporally (Owen 2002; Fontugne et al. 2004; Ortlieb et al. 2011; Latorre et al., 2015).

The main aim of this study is to resolve the chronology of the Pica 8 cemetery, and in particular whether the observed isotopic/dietary variability is synchronic or diachronic (the term 'synchronic' in this context is not meant to imply that all the burials are contemporary, but rather that the observed isotopic variation bears no relationship with chronology). To achieve this aim, nine paired ^{14}C determinations were undertaken on human bone and camelid textiles in order to address the marine reservoir offset for this region and period. We expect collagen to be most affected by the MRE, whereas the camelid textiles should be entirely unaffected. In addition to the paired dates, an additional five burials were selected for ^{14}C dating. No textiles or other appropriate terrestrial dating materials could be associated with these individuals, but they were included in order to provide more comprehensive spatial coverage of the various sectors of the Pica 8 cemetery.

6.2 Chronological context of the Tarapacá Cultural Area

Much of the current LIP chronological framework for the Tarapacá cultural area is based on ceramic seriation. The main pottery type that characterizes this cultural complex is known as Pica Charcollo (PCH) with dates from AD 950-1470. The Pica Charcollo pottery style also presents variants such as Pica Chiza (PCHZ) and Pica Gris Alisado. All together, these three types date to AD 900–1445 by Thermoluminescence (TL) (Uribe et al., 2007), falling in the LIP range.

Only three radiocarbon dates on archaeological material have been obtained so far for the interior of this cultural area, specifically from the Pica 8 cemetery (Núñez 1976).

However, two of them (dates on maize cobs) present calibrated dates post AD 1500, clearly too recent to be related with a pre-Columbian cemetery. The third date falls inside the LIP range, between cal AD 902-1270 (camelid textile sample from tomb 6: IVIC-173: 930 ± 90 BP). Three dates on human bone collagen, published by Uribe et al (2007) for the Pica 8 cemetery, show their clear association with the LIP. These dates come from individuals SDT11 (Beta 220922: 1050 ± 40 BP; AD 900–1030), B0447 (Beta-220923: 900 ± 40 BP; AD 1030–1230), and B0438 (Beta-220924: 810 ± 40 BP; AD 1170–1280) (Uribe et al., 2007). However, since there is evidence of the consumption of marine resources at Pica 8 (Santana et al. 2015a), the dates may be subject to the MRE. No $\delta^{15}N$ measurements were made for these individuals when dated, limiting the usefulness of these results. A new bone sample was obtained from only one of these individuals, B0447. This individual has already been analysed for stable isotope analysis and will be analysed again in this research for radiocarbon dating.

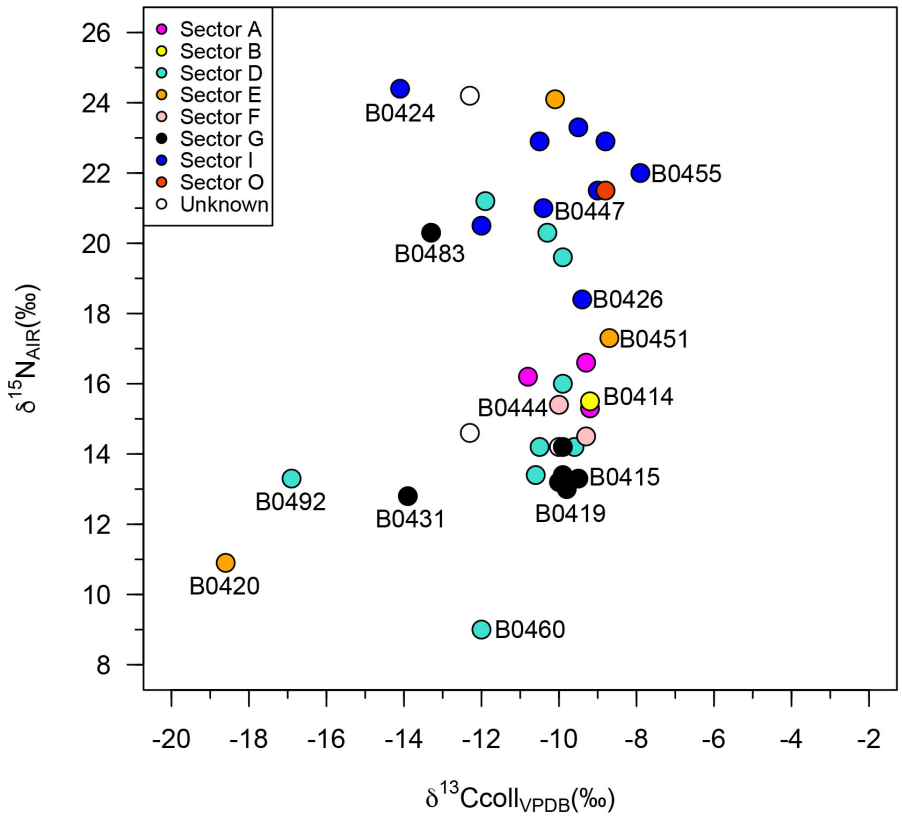


Figure 6.1. Bivariate plot for $\delta^{13}C_{coll}$ and $\delta^{15}N$ values from the different sectors of the Pica 8 cemetery.

6.3 The Marine Reservoir Effect in northern Chile

The marine reservoir effect (R) is defined as the difference in the radiocarbon content present in terrestrial and marine organisms, with the latter being depleted in ^{14}C (Ortlieb et al., 2011; Carré et al., 2015). In contrast to terrestrial environments and organisms, the CO_2 present in the deep ocean is not equilibrium with the atmosphere. Thus, dates obtained for modern marine organisms will be much older compared to those from the terrestrial biome. This difference in ages has been estimated in around 400 yr, the global ocean R average (Ortlieb et al. 2011). However, R can also vary significantly depending on latitude and upwelling within particular regions, as well as inputs from freshwater systems, which can have their own reservoir offset (however, these are not a factor in northern Chile, which has no significant watercourses, at least for this particular area). This additional local variation, designated ΔR, needs to be considered when correcting the radiocarbon dates for any marine reservoir effect in addition to the global R average (Ortlieb et al. 2011; Carré et al. 2015).

Northern Chile, together with southern Peru, is characterized by a strong upwelling system, mixed with different currents coming from the equator and the Antarctic (Ortlieb et al. 2011; Latorre et al. 2015). The most important of these is the Humboldt Current, also known as the Peru-Chile Current, characterized by its high productivity and biodiversity. At the same time, it brings dissolved inorganic carbon depleted in ^{14}C from the ocean bottom to the surface (Latorre et al. 2015). There is relatively limited data pertaining to the region's ΔR value. The ^{14}CHRONO Marine Reservoir Database (http://calib.qub.ac.uk/marine/) shows seven data points for northern Chile/southern Peru. These data show that modern local ΔR values range from less than 50 yr up to almost 400 yr. Most of the information available in the database comes from the study done by Ortlieb et al. (2011). So far, these authors carried out the most complete study on the local marine reservoir effect for northern Chile and southern Peru, analysing

modern and ancient samples. Using a total of 46 paired dates of marine and terrestrial samples their data show a considerable variability in ΔR through time. During the early Holocene ΔR values average 511±278 yr, decreasing significantly during the middle Holocene to 226 ± 98 yr, before increasing again in the late Holocene to 355±105 yr. The authors relate this variability to changes in upwelling. A possible effect of the El Niño Southern Oscillation is suggested for the late Holocene in particular (Ortlieb et al., 2011).

A recent study by Latorre et al. (2015) on archaeological shell middens from Caleta Vitor, northern Chile, shows ΔR values somewhat higher than those obtained by Ortlieb et al. (2011) during the early and mid-Holocene, emphasizing the difficulties involved in determining very precise ΔR values. Compounding this is the fact that there is spatial as well as temporal variation. The upwelling system for northern Chile shows significant differences compared to central Chile. Carré et al. (2015) provide an average ΔR value of 168±69 yr for the late Holocene in central Chile, compared to 355±105 yr for northern Chile. The difference between the early Holocene of central and northern Chile is even higher, with ΔR values of 31±156 yr and 528±301 yr, respectively.

6.4 Materials and Methods

A total of 23 samples from Pica 8 were selected for radiocarbon dating, comprising adult rib samples and one hair sample from 13 distinct individuals, nine of which could be paired with associated textiles to address the marine reservoir effect (Tables 1). Adults were chosen to avoid complications in the interpretation of $\delta^{15}N$ values due to nursing effects. All the human bone and hair samples were previously analysed for $\delta^{13}C_{coll}$ and $\delta^{13}C_{ap}$ and $\delta^{15}N$, with ca. one-third argued to show considerable

consumption of marine resources, with others indicating a mixed marine and terrestrial diet, and a few suggesting a largely terrestrial diet (Figure 6.1) (Santana-Sagredo et al. 2015a). The burials at Pica 8 were found in a naturally mummified state with the bodies completely preserved.

Sample	Inventory Number	Sector	OxA-Number	$\delta^{13}C_{coll}$	$\delta^{15}N$	$\delta^{13}C_{ap}$	R-C Age (BP)	Sigma	Date (cal AD)
Bone (Rib)	B0414	B	33425	-9.2	15.5	-3.6	1035	27	993-1147
Textile (Tunic)	B0414/ A03827	B	32817	-	-	-	908	33	1047-1266
Bone (Rib)	B0415	D	33426	-9.6	14.2	-3.9	896	30	1070-1266
Textile (Bag?)	B0415*	D	32818	-	-	-	900	32	1051-1266
Human hair	B0460	D	32728	-12.0	9.0	-	935	24	1046-1217
Textile (Tunic)	B0460/ A03829	D	32819	-	-	-	910	32	1046-1264
Bone (Rib)	B0492	D	33429	-16.9	13.3	-11.7	980	28	1028-1163
Textile (Bag)	B0492/ A03830	D	32882	-	-	-	954	26	1039-1191
Bone (Rib)	B0420	E	V-2645-51	-18.6	10.9	-13.0	744	24	1271-1383
Textile (Bag?)	B0420*	E	32820	-	-	-	634	32	1301-1414
Bone (Rib)	B0451	E	V-2648-36	-8.7	17.3	-3.9	948	25	1045-1207
Textile (Hairball)	B0451/ A03841	E	32972	-	-	-	1222	31	769-969
Bone (Rib)	B0444	F	33427	-10.0	15.4	-4.6	978	28	1029-1173
Textile (Tunic)	B0444*	F	32821	-	-	-	869	33	1161-1272
Bone (Rib)	B0447	I	33428	-10.4	21.0	-4.0	896	28	1071-1266
Textile (Hair bundle)	B0447/ A03839	I	33508	-	-	-	776	31	1046-1272
Bone (Rib)	B0455	I	V-2645-55	-7.9	22.0	-3.6	849	24	1189-1274
Textile (Loincloth)	B0455*	I	32883	-	-	-	831	25	1211-1280
Sample	**Inventory Number**	**Sector**	**OxA-Number**	**$\delta^{13}C_{coll}$**	**$\delta^{15}N$**	**$\delta^{13}C_{ap}$**	**R-C Age (BP)**	**Sigma**	**Date (cal AD)**
Bone (Rib)	B0419	G	V-2648-35	-9.9	13.4	-4.5	1041	25	991-1145
Bone (Rib)	B0431	G	X-2645-54	-13.9	12.8	-8.2	1192	25	788-987
Bone (Rib)	B0483	G	V-2645-56	-13.3	20.3	-8.5	1293	25	682-876
Bone (Rib)	B0424	I	V-2645-52	-14.1	24.4	-10.5	1199	25	778-981
Bone (Rib)	B0426	I	V-2645-53	-9.4	18.4	-4.4	819	24	1219-1280

Table 6.1. Radiocarbon ages and $\delta^{13}C_{coll}$, $\delta^{15}N$, $\delta^{13}C_{ap}$ values for paired and unpaired samples from Pica 8.

Unfortunately scholars removed all the soft tissue during the 1960s and 1970s in order to facilitate osteological analysis (Aspillaga 2016 pers. comm.).

Nine camelid textile samples were selected for paired with human bone. These were all in direct associated with the body, comprising tunics and wrappings for the deceased, a textile bag, a loincloth, a camelid hair bundle, and one example of a camelid 'hairball' found inside the mouth of one individual. The practice of leaving hairballs inside the mouths of dead bodies has been documented by Agüero (2016, pers. Comm), for the coastal site of Pisagua, dating to the Formative Period.

Given the excellent preservation at the site, neither the bone nor textile samples were treated with any consolidants or conservation materials.

All the analyses were carried out at the Oxford Radiocarbon Accelerator Unit (ORAU), University of Oxford. Bone collagen samples, as well has hair and textile (camelid wool) samples were pre-treated following the protocols of Brock et al. (2010). All human bone collagen samples had been previously prepared for stable isotope analysis following standard protocols at the Research Laboratory for Archaeology and the History of Art, University of Oxford (Santana-Sagredo et al. 2015a).

Five bone collagen samples presented high C/N ratios (above 3.45, following the stricter ORAU standards rather than DeNiro's (1985) widely accepted range of 2.9 to 3.6 for dietary stable isotope research). For this reason, it was necessary to perform a base wash with acetone, methanol and chloroform on these five samples twice. Since the samples presented excellent preservation, they appear to have still contained traces of lipids, presumably responsible for the slight elevation in their C/N ratios. After applying the base wash, the C/N ratios decreased to ca. 3.1 to 3.2.

All the samples were combusted in a CF-IRMS system – Carlo ERBA NA 2000 coupled to a gas source IRMS, Sercon 20/20 (Brock et al. 2010). CO_2 gas was collected and graphitized, and analysed in the HVEE AMS system of the ORAU. The resulting ^{14}C determinations were calibrated using the SHCal atmospheric curve (Hogg et al., 2013) in OxCal v 4.2.4 (Bronk Ramsey 2013). Statistical analyses were undertaken in The R Project for Statistical Computing (2003)

6.5 Results

The results are presented in Tables 1 (paired and unpaired samples). As expected, most fall inside the temporal range for the LIP (cal AD 993–1414). Unexpected, however, are the very limited offsets in ^{14}C years observed in the paired dates for associated textile and bone samples (Figure 6.2). This includes the individuals extremely enriched in ^{15}N (with the highest having $\delta^{15}N$ values of 21–22‰), which were expected to exhibit offsets on the order of some centuries (i.e., diets dominated by marine protein). In one pairing (individual B0451) the date for the 'textile' – a ball of camelid hair placed inside mouth – is actually significant older than the bone, by ca. 270 ^{14}C yrs. We suspect that this was a curated object, or one encountered accidentally from an earlier context, and retained as an object of some ritual significance. In any case, it is excluded from further consideration.

Leaving aside the above outlier, the largest offset observed between the paired human bone and textile results is 127 ^{14}C years. Three other pairings exhibit offsets of 109 to 120 years, giving an average offset of 117±9 ^{14}C yrs for this group of four. Surprisingly, the $\delta^{15}N$ values for these individuals range from 10.9‰ to 21.0‰, spanning nearly the entire range of those sampled for paired dating (and incorporate a substantial part of the variation in $\delta^{15}N$ across the site as a whole – Santana-Sagredo et al. 2015). This

group includes the individual (B0455) with the highest $\delta^{15}N$ value of 22.0‰. Single and multiple linear regression analyses show no statistically significant correlations between any of the human stable isotope measurements ($\delta^{13}C$ on collagen and apatite, and $\delta^{15}N$ on collagen) and the observed offsets in ^{14}C years (Figure 6.3).

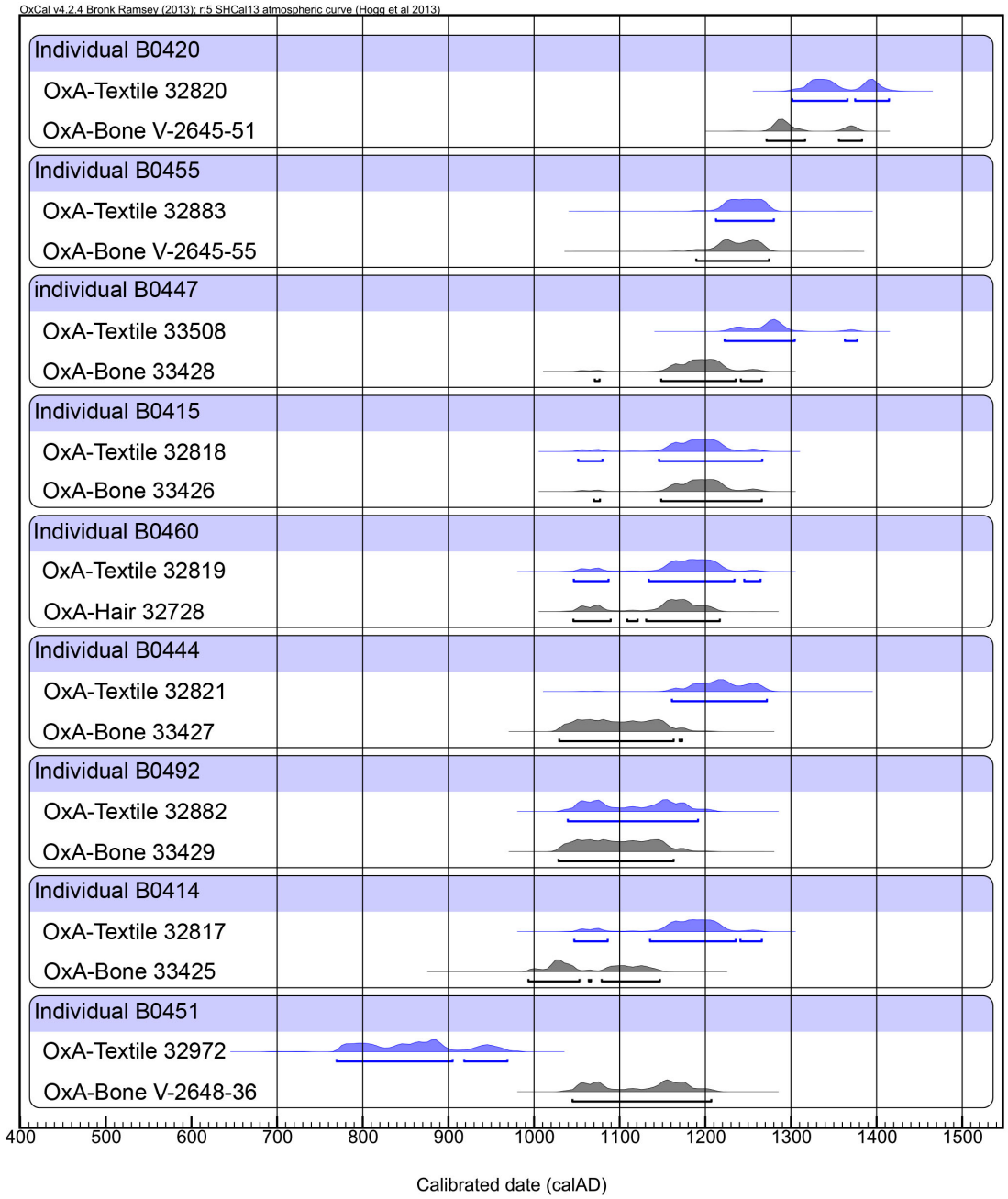


Figure 6.2 Calibrated paired dates of bone collagen and textiles from 9 burials of Pica 8.

Four of the five results for the remaining unpaired dates on human bone are largely consistent with the Late Intermediate Period (Figure 6.4). However, one individual (B0483) can be placed at the end of the Formative Period for the Tarapacá cultural area. The results for two other individuals (B0424 and B0431) exhibit probability distributions crossing the boundary between the Late Formative Period and the LIP.

6.6 Paired ^{14}C dates and the MRE

The paired dating exercise indicates the presence of two groups, one with a relatively small but significant offset of 117±9 ^{14}C yr, and the other showing no offset at all (excluding the outlier, B0451). This is a surprising outcome, given the assumed importance of marine foods in the diets of some individuals at Pica 8, combined with the strong upwelling regime characterizing northern Chile's coast, leading to an estimated ΔR for the late Holocene of 355±105 yr (Ortlieb et al. 2011; Latorre et al. 2015). When added to the global ocean MRE of 400 yr, the combined offset would be on the order of 650–850 yr for an individual obtaining most or all of their protein from the sea. Using this range, the observed average offset of 117±9 years for four individuals implies a contribution of marine foods on the order of between 12.6% and 19.4‰, i.e., the observed offset in the four paired dates as a proportion of the expected total marine reservoir offset in a 100% marine consumer, taking into account the errors associated with these estimates:

R (355±105)	Total MRO	Observed offset (117±9)	%marine
Max R: 460 yr	860 yr	Min: 108	19.4%
Min R: 250 yr	650 yr	Max: 126	12.6%

This is substantially lower than what would have been predicted on the basis of the stable carbon and nitrogen isotope values (Figure 6.1). Moreover, the lack of any significant correlation between the stable isotope measurements and the observed ^{14}C

offsets is difficult to explain (see below). Certainly other studies have found significant predictive relationships in other contexts (Price et al. 2007; Schulting et al. 2015).

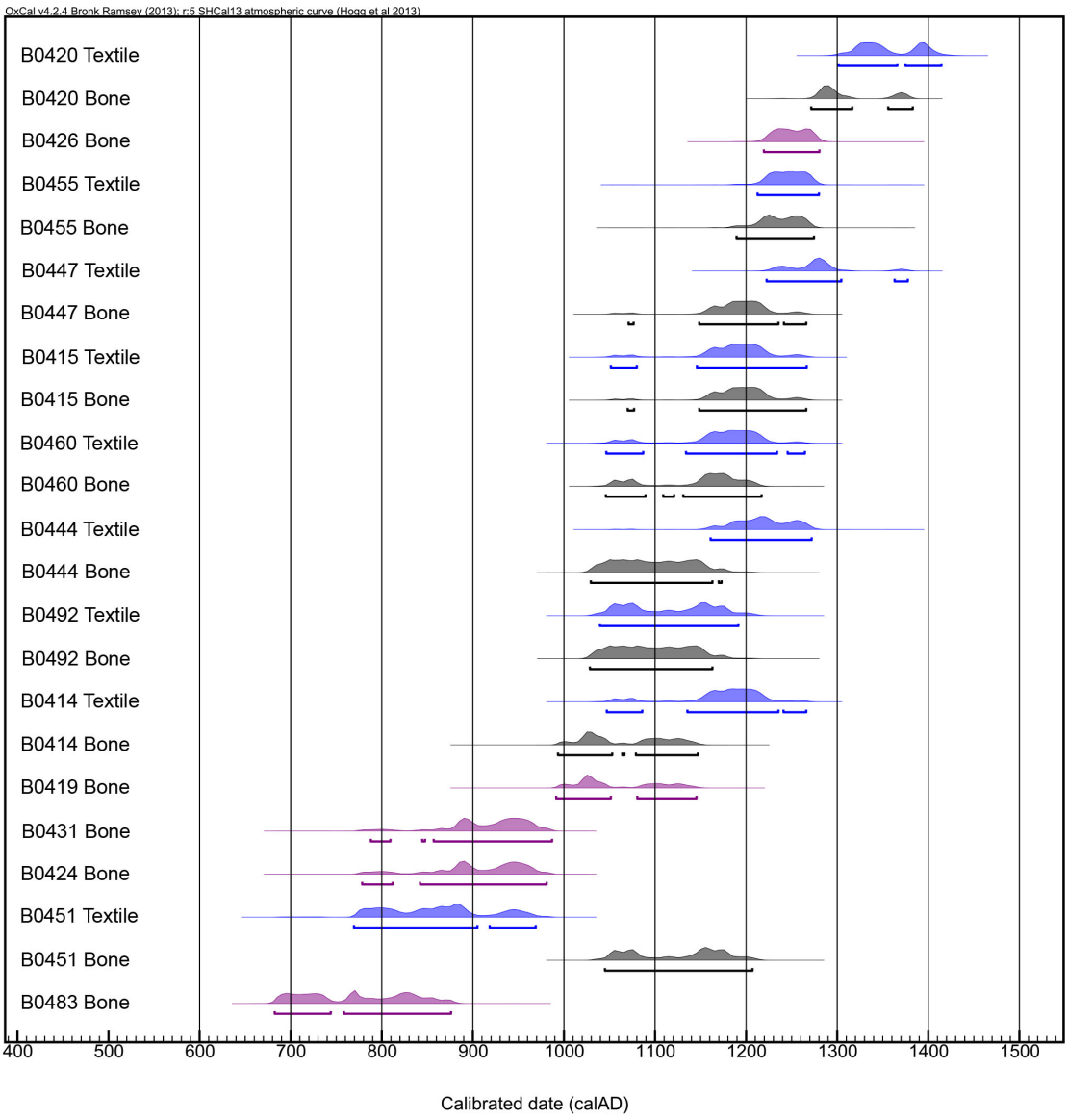


Figure 6.3. Calibrated dates for paired bone collagen (grey) and textile (blue) and unpaired bone collagen (violet) samples from Pica 8.

These results challenge the previous interpretation of the high $\delta^{15}N$ results (up to 24.4‰) at Pica 8 as indicating a substantial contribution of marine protein in the diets of some individuals. This is a reasonable assumption, considering the average $\delta^{15}N$ values of between 19.2±2.1‰ and 18.5±1.7‰ for modern northern Chilean marine fish and sea mammals, respectively (Tieszen and Chapman, 1992). In addition, there is actual evidence for marine resources in the cemetery at Pica 8 (Núñez, 1984). However, there are other factors that could affect their nitrogen isotopic measurements. First of all, it is well known that the dry conditions of the Atacama Desert (and other arid regions of the world) can significantly affect the nitrogen isotopic composition of soils, plants and animals (Evans and Ehleringer 1994; López et al. 2013; Díaz et al. 2016). Thus, human values of ca. 15‰ could be related to the consumption of plant or animal resources with high $\delta^{15}N$ values, and not necessarily a marine diet. However, there is still a substantial gap between this and the highest observed values of >20‰.

Pica 8 dates to the LIP in which agriculture was fully developed and consolidated in the south-central Andes. Early European chronicles show strong evidence for the use of fertilisers for the agricultural activities in the Atacama Desert (Frezier 1717; Cieza de León, 1932; Diez de San Miguel 1964), as discussed in Chapter 4. Different types of fertilisers were used, including llama dung, seabird guano and anchovy heads (Parsons and Psutty 1975; Julien 1985). Thus, it would not be surprising that the Pica 8 community fertilised their crops, particularly given the otherwise sandy soils of the Atacama. The use of any of these manures would have undoubtedly elevated soil ^{15}N composition, in turn reflected in crops and humans and animals consuming them. In particular, the impact of the use of seabird guano on crops has been clearly demonstrated by the experimental studies carried out by Szpak et al. (2012a,b; 2014), with maize $\delta^{15}N$ values ranging 20 to 40‰. Thus, the consumption of crops fertilised

with seabird guano would increase human $\delta^{15}N$ values significantly. Since the crops would only uptake nitrogen from the manure and not carbon (plants uptake their carbon for photosynthesis directly from the atmosphere in the form of CO_2.), seabird guano would leave plant ^{13}C and ^{14}C unaffected.

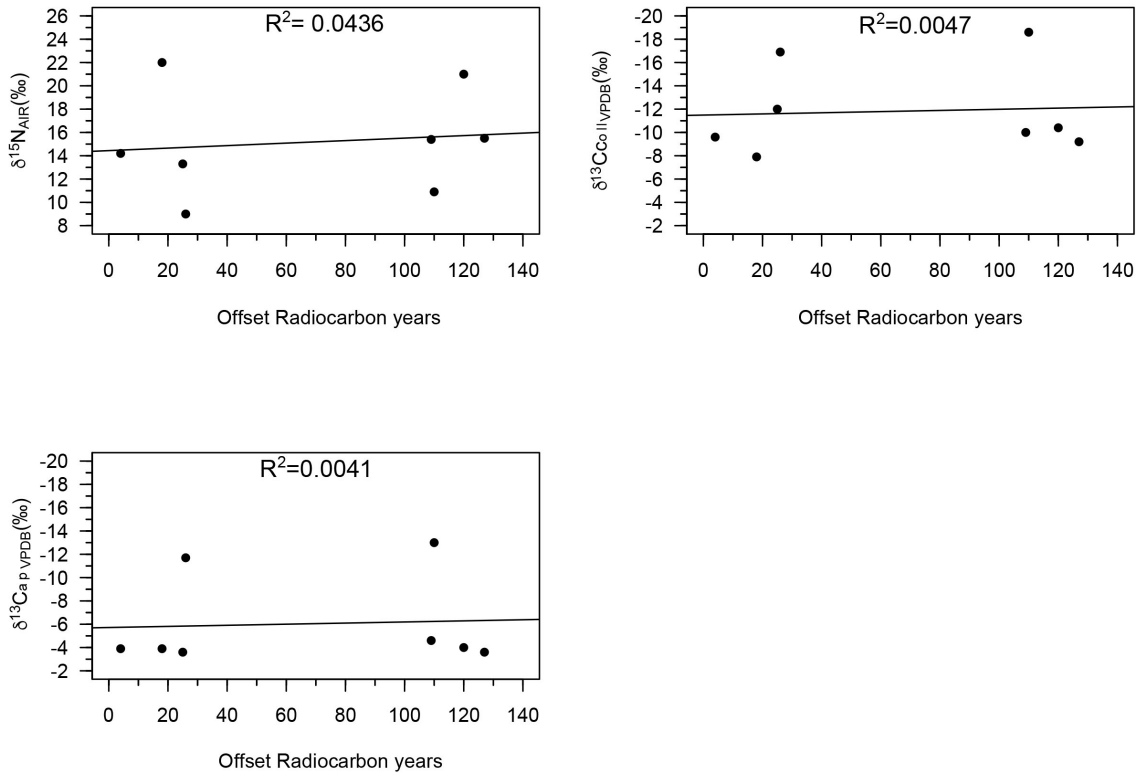


Figure 6.4. Bivariate plots for (a) $\delta^{15}N$ values, (b) $\delta^{13}C$coll values and (c) $\delta^{13}C$ap values and the offset radiocarbon years calculated from the paired bone collagen and textile samples of Pica 8, showing the almost absence of correlation between them.

Thus, the consumption of crops fertilised with seabird guano presents a viable alternative to marine foods in the explanation of high $\delta^{15}N$ values above 20‰. The interpretation of elevated ^{13}C in contexts with access to both C_4 plants (maize) and marine foods is always problematic, and so taking this isotope into consideration does not appear to offer any solutions, except in the case of individuals who clearly partook of neither food. This problem, together with the enormous potential unrelated variability in ^{15}N introduced by the combination of marine foods and manuring with seabird guano

could explain the lack of any predictive relationships between stable isotope measurements and ^{14}C offsets.

The results obtained here also contrast with a previous case reported by Cases et al. (2008) for northern Chile, in which a considerable offset was observed between an ancient human body and its textile. This individual was found isolated near the María Elena Nitrate Mine in the Atacama Desert. Muscle tissue from the individual yielded a radiocarbon determination of 2390±70, as well as one of textiles associated with it. Radiocarbon dating was carried out both on the main textile and on a repair patch, presenting very similar dates (1890±40 and 1870±40, respectively), associated with the Formative Period. However the human muscle tissue was 640 years older compared to the textiles. This individual also had high $\delta^{13}C_{coll}$ and $\delta^{15}N$ values, -13.7‰ and 21.6‰, respectively, comparable to the highest values at Pica 8. In this case a marine diet is strongly suggested by the individual's nitrogen isotope composition (Cases et al., 2008). In addition, the individual was found in direct association with dry fish (Cases et al. 2008). The contrasts observed between this particular case and the Pica 8 paired dates could be explained by temporal and dietary differences. Since this individual dates to the Formative Period, a significant dietary contribution of maize is unlikely. Agriculture by this time was still experimental and crops did not form a dietary staple (Santana et al. 2012; García et al. 2014; Santana-Sagredo et al. 2015b). Therefore, the use of seabird guano would not yet have featured, so that the high $\delta^{15}N$ value seen in the María Elena individual was likely to be exclusively the result of a marine diet.

6.7 Diet diversity in Pica 8: Temporal difference or synchronic cultural aspects?

The paired dates obtained here strongly suggest that the isotopic variability observed at Pica 8 is not related to diachronic change. On the contrary, the limited range of dates for all but one individual, of between AD 990-1270 years, suggests that

considerable heterogeneity existed within a broadly contemporaneous community. This is further emphasized by the absence of any chronological trends between the stable isotope results and the calibrated dates. However, the lack of a predictive relationship between the stable isotope values and the small marine reservoir offset that was identified for a subset of individuals requires a re-consideration of the source of the isotopic variability at Pica 8. Rather than marine foods as previously propose (Santana-Sagredo et al. 2015a), this is likely to be differential access to crops manured with seabird guano, particularly maize, which by the LIP had become an important staple (Santana-Sagredo et al. 2015b). Thus, a link with the coast is still indicated, and no doubt included the transportation of some marine foods, which after all were present in the cemetery and also indicated in the diets of some individuals by the ^{14}C offsets. But more importantly for explaining the isotopic variability – more notably the highly enriched ^{15}N – is the access to seabird guano that these exchange links (kin-based?) may have facilitated. What is most interesting, then, is that the resulting fertilised crops appear not to have been made available to the entire community at Pica 8.

The textiles at Pica 8 also hint at different origins and connections. For instance, some individuals (B0414, B0415, B0444 and B0460) were interred with textile styles typically associated with the local Pica-Tarapacá culture. However, in this case they cross-cut the different cemetery sectors (B, D and F). The hair bundle associated with individual B0447 is a common trait found in the coast of the Tarapacá cultural area. This individual is buried in sector I where most of the marine evidence was found. It shows a $\delta^{15}N$ value of 21‰, and an offset of 120 ^{14}C years in the paired dating. Yet, since other individuals with equally high $\delta^{15}N$ values show no offset, this in itself cannot be understood as indicating access to marine foods.

One individual (B0492) from sector D was associated with a non-local bag. This type of bag was used for burden camelids in order to carry objects and food. The textile style

has also been observed in the Atacama Oases (Agüero, 2006 pers.comm.), specifically in Quitor and Solcor. However, it is not possible to associate it directly with the Atacama Culture, since it could also have an origin in the highlands or somewhere else. Strikingly, this individual presents isotopic values for carbon and oxygen isotopes that are clearly non-local, marking it as a clear outlier (Santana et al. 2015) in Pica 8.

The most peculiar case, as mentioned before, is individual B0451 and the hairball found inside its mouth. This was an ancestral practice dating to the Formative Period in the Tarapacá coast. In fact, the hairball dates (AD 796-969) to the Formative Period. One possible explanation for this is that the hairball was removed from a burial in the coast and brought inlands to the Pica oases. Another alternative could have been that they kept the hairball inland since the Formative Period and re-used it during the LIP. In any case, it is associated with a typical coastal practice.

Individual B0420 has a relatively low δ^{15}N value of 10.9‰ and it is also an outlier for its carbon and oxygen isotopes (Santana et al. 2015a). At cal. AD 1271-1383, this is the most "recent" of the dated individuals. However, the camelid textile associated with this individual has an offset of 110 years (cal AD 1301-1414) compared to the human bone collagen, suggesting the consumption of ca. 15% marine protein, but then this seems incommensurate with the δ^{15}N value. Unfortunately, this textile (possibly a bag) in particular was in a very poor state of preservation and it not possible to identify its type, style and cultural association.

The only dates that could suggest a temporal difference inside the cemetery are B0483, together with individuals B0424 and B0431. Individual B0483 (cal AD 682-876) clearly falls in the Late Formative Period for the Tarapacá cultural area. Individuals B0424 (cal AD 778-981) and B0431 (cal AD 788-987) present dates with probability distributions falling between the Late Formative Period and beginnings of the LIP. It is

possible that both are affected to a small extent by the MRE. A high marine diet was previously suggested for individual B0424 considering the high $\delta^{13}C_{coll}$ and $\delta^{15}N$ values of -14.1‰ and 24.4‰, respectively together with a $\delta^{13}C_{ap}$ value of -10.5‰, sufficiently low to propose an absence of maize in the diet (Santana et al., 2015c). However, given the results of the paired dating program, the inference of a high marine diet is now made problematic. Nevertheless, the fact that half of the individuals in the paired dating exercise exhibited offsets of ca. 100 ^{14}C years makes a moderate contribution of marine foods a relatively uncontroversial claim.

As can be seen, the cultural variability of Pica 8 was reflected in the dietary composition of the population together with the textile styles associated with the burials. The dates clearly show a synchronic occupation of the cemetery suggesting an important multi-culturalism occurring during the LIP in Pica 8. Even though the individuals consumed different types of diets and were buried with diverse textile types and styles, they were buried in the same cemetery. Identity and ethnicity factors could have played a major role in Pica during the LIP, leading to the co-existence of different cultural groups.

Our findings have important implications for northern Chile's prehistory during the LIP, giving new insights on the socio-cultural dynamics of the Pica-Tarapacá complex.

6.8 Conclusions

Paired human-textile ^{14}C dating from nine graves at Pica 8 were undertaken as a first step to understanding the potential impact of the MRE on the chronology of the site. The results show two clear groups: one with a ca. 100 ^{14}C-year offset and the other with no offset. The former is consistent with a contribution of ca. 12-19% of marine protein, although this is considerably less than was expected. Moreover, no

correlations were observed between the high $\delta^{15}N$ values – or indeed with $\delta^{13}C$ measurements on collagen and apatite – and the offset between the paired dates. These results question the use of nitrogen stable isotopes in order to evaluate the MRE on the radiocarbon dates for northern Chile for the LIP. The possible effect of aridity and the use of fertilisers, particularly seabird guano and anchovies heads, could considerably affect the nitrogen isotopic composition of crops, animals and finally humans. Since fertilisers should not affect the carbon composition of the crops, no impact of the MRE would be observed on them nor on the individuals consuming them. This could be a possible explanation for the individuals with high $\delta^{15}N$ values and almost no offset between the paired dates. However, the MRE for northern Chile and southern Peru is still little known. This situation complicates the dating and interpretation of samples associated with the coast. We suggest that the effect found in this paper will be largely restricted to the LIP and later periods in the study region, since maize agriculture was of limited importance in the preceding Formative period. This is also consistent with previously reported offsets with paired human-terrestrial samples dating to this time (Cases et al. 2012).

The main archaeological question posed here was whether the previously noted high isotopic/dietary diversity was related to temporal change, or whether it reflected variation within a living community. The results appear to favour the latter explanation, with no relationship being found between the stable isotope measurements and radiocarbon determinations. This in turn suggests the importance socio-cultural aspects such as identity and ethnicity in structuring foodways, and in determining differential access to marine resources, both in the form of food but, more importantly, in the form of seabird guano to fertilise crops, especially maize, grown at the Pica oasis. While this is an attractive explanation, an alternative does exist, which is that access to seabird guano was intermittent on a decadal cycle (i.e., on a timescale not amenable to radiocarbon dating), and so the observed isotopic variability could reflect

short-term fluctuations in manuring practices. We find this improbable, since the advantages of the system once in place should have been readily apparent, though this in turn begs the question of why not everyone in the community had access to fertilised crops. Thus, while answering one question, this study has raised others – not an unusual outcome in archaeology or indeed any science.

Chapter 7

Mobility patterns in the Atacama Desert during the LIP

The study of human mobility patterns is essential for better understanding the social and cultural dynamics that characterised the LIP. So far, the dietary evidence presented in Chapter 5 does not support the idea of *altiplano*-colonies in the Atacama Desert lowlands (Murra, 1972), but rather suggests more local traditions. However, it would be helpful to evaluate more directly the place of origin of the individuals that inhabited these sites. In order to do so, this chapter aims to study the mobility patterns in northern Chile during the LIP through the application of strontium and oxygen isotope analyses on ancient human teeth and bone.

A secondary aim of this chapter is to build a local bioavailable strontium baseline for the study area based on plant and animal remains. This was considered essential in order to better interpret the possible places of origin of the individuals analysed here. A new baseline was also necessary for the area, since, previous estimations of the 'local' ranges for northern Chile have been based on very little data.

7.1 Stable Oxygen Isotopes for the study of residential mobility

Oxygen isotopes enter the human body primarily through water consumption reflecting the isotope composition of the water source (Luz et al., 1984; Longinelli, 1984;). Food can also contribute to the oxygen isotope composition, although this occurs to a lesser degree in the case of omnivores (Daux et al., 2008). The meteoric oxygen isotope composition of water sources will change depending on factors such as amount of rainfall, latitude, altitude, temperature and evaporation (Rozanski et al., 1993; Sharp, 2007). At higher altitudes, such as those of the Andes Mountains, water should present an isotopic composition depleted in ^{18}O, due to altitude and cold temperatures that

allow precipitation to occur, as mentioned in Chapter 2 (Magaritz et al., 1990; Rozanski et al., 1993; Aravena, et al., 1999; Sharp, 2007). On the other hand, $\delta^{18}O$ values expected for the lowlands should be higher, such as in the Atacama Desert, because of the high temperatures, lack of precipitation but due to mainly high evaporation rates (Magaritz et al., 1990; Rozanski et al., 1993; Aravena et al., 1995; Aravena et al., 1999; Sharp, 2007). ENSO (El Niño-Southern Oscillation) cycles can also affect and change the amount of rainfall in the Andes. At the same time, cultural activities such as water boiling or *chicha de maíz* preparation, and breastfeeding can cause enrichment in ^{18}O (Wright and Schwarcz, 1998; White et al., 2004a,b; Knudson, 2009; Turner et al., 2009).

Oxygen isotopes are routed to the bioapatite molecule, and can be found within the form of phosphate and carbonate groups (LeGeros, 1991). Tooth enamel and bone apatite will reflect the oxygen isotope composition of the water consumed in different periods of the individual life. Enamel will show the isotopic values obtained during the mineralisation of the tooth in question (Hillson, 1996). Each tooth type will develop and mineralise at a different moment in life, but mainly during childhood. Bone turnover in contrast, occurs at different rates, approximately every 7-10 years (Robins and New, 1997; Hedges et al., 2007).

7.2 Strontium isotopes and its applications to human mobility

Radiogenic strontium isotope composition has become a powerful tool for tracing human mobility and provenance in the past (e.g. Price et al., 1994; Sealy et al., 1995; Price et al., 2000; Price et al., 2004; Bentley et al., 2004; Bentley 2006; Evans et al., 2009). The technique is based on the distribution of strontium isotopes in the regional geology of the study area. Strontium has four isotopes. ^{87}Sr is a product of radioactive decay, while the others are stable (88, 86, 84). The strontium isotope composition in

natural materials is expressed in ratios. In contrast to stable carbon, nitrogen and oxygen isotopes, strontium isotopes do not go through fractionation process because they present a very small relative mass difference (Faure, 1986). Generally, strontium isotopes are expressed as $^{87}Sr/^{86}Sr$, because ^{87}Sr and ^{86}Sr have similar abundances (Price et al., 1994). However, variations in $^{87}Sr/^{86}Sr$ will occur, due to the radiogenic nature of ^{87}Sr. Rubidium-87 decays to ^{87}Sr through time (Faure, 1986; Faure and Powell, 1987). Thus, the $^{87}Sr/^{86}Sr$ differs between geological regions depending on the age and the type of local bedrock (Faure, 1986; Faure and Powell, 1987). Older rock with higher initial ^{87}Rb shows greater concentrations of the daughter product, ^{87}Sr (Faure, 1986; Faure and Powell, 1987). This means that the local geology can be characterised by the relative proportions of $^{87}Sr/^{86}Sr$.

Strontium isotopes are released to the soils and water through weathering of rocks (Faure, 1986). Waters will tend to show an average value of the geologic composition of the local area. However, this will depend on the weathering rates and the possible (small) amount of oceanic Sr in the rainwater. The world's current seawater has a standard average $^{87}Sr/^{86}Sr$ ratio of 0.7092 coming from continental weathered crust (Veizer, 1989; Hodell et al., 2004; Bentley, 2006) and water rock of oceanic ridges.

Another important factor influencing strontium values from the rocks is the topography and environment of the region. There are inputs and outputs, the former including atmospheric deposition and weathering, and the latter rivers and groundwater. In places with significant topography and differences in altitude (Aubert et al., 2002), such as the Andes, the erosive action from the high relief and run-off of water and soils from one place to the other can mix strontium, masking the original $^{87}Sr/^{86}Sr$ composition. Rivers also play a role on the bioavailable Sr composition of a region, since they carry dissolved mineral, including Sr, from their sources and pathways (Capo et al., 1998; Beard and Johnson, 2000).

Strontium isotopes are passed into the food chain from water, soil and sediments by plants (Bentley, 2006). This is how bioavailable strontium finds its way into the foodweb, and which is ultimately what is measured in plants, bones and teeth of consumers. In the case of animals and humans, strontium is incorporated into the mineral component, or biological apatite, of bones and teeth via ingested food. Strontium substitutes for calcium in the apatite molecule because they have very similar ionic radii (Bentley 2006).

Defining bioavailable strontium for a region, place or site is not straightforward. It is usually accomplished by measurement of local plants, non- migratory animals, and sometimes soils and even human tissues (Price et al., 2004; Evans et al., 2009; Snoeck et al., 2009). This is because the $^{87}Sr/^{86}Sr$ ratios of the rock minerals can show significant variability, depending on the type of mineral and weathering rate. For example, granites tend to have heterogeneous mineral compositions, including feldspar and biotite that differ in $^{87}Sr/^{86}Sr$ ratios, and the weathering products in sediments will differ (Evans et al., 2009).

Following this, it is of great relevance for mobility and provenance studies to have a map of the bioavailable strontium isotope values for the research area. This information can be obtained from the enamel or bone of small mammals (Price et al., 1994, Price et al., 1995; Price et al., 2004, Knudson and Price, 2007), with a very reduced mobility area, or from plants of the region. However, the problem with animal samples is that, depending on species, they have wide ranges of mobility through different geological regions, showing considerable more variability in their $^{87}Sr/^{86}Sr$ ratios (Evans et al., 2009).

Plant samples can actually be a better tool for reconstructing bioavailable strontium maps, since they show very consistent values for different geologic terrains (Bentley,

2006; Evans et al., 2009, Snoeck et al., 2016). However, modern plants can be affected by anthropogenic factors such as fertilisers.

7.3 Geology of the Atacama and Tarapacá Cultural Areas

The Andes Mountains surrounding the Atacama are comprised of basaltic andesites, dacites and ignimbrites dating to the Quaternary (Godoy et al., 2014; SERNAGEOMIN[1]). The Atacama Oases, next to the Andes, show a different mix of gravel, sand, silt, alluvial deposits and ignimbrites (SERNAGEOMIN).

For the Tarapacá Cultural Area different types of geological compositions are observed. The valley where Quillagua is located is mainly formed by alluvial deposits, with a mix of different sediments, probably coming from the Andes or other localities in the surrounding area. Limestone and gravels dating to the Pliocene and Upper Miocene dominate the geological composition of this locality (SERNAGEOMIN).

The geological composition of the coast at Iquique and Antofagasta presents granite rocks as well as basaltic andesite and sediments, probably dating to the Cretaceous period. Iquique also shows Pleistocene rocks associated with aeolian processes. The *Pampa del Tamarugal* and Pica oases on the other hand, show a composition with sandstone, limestone, lutite and ignimbrites (but less than in the Atacama Oases) as its main rock minerals, dating to the Oligocene and Miocene periods (SERNAGEOMIN).

[1] Information obtained from the Servicio Nacional de Geología y Minería's website www.sernageomin.cl (Chile)

7.4 Oxygen and $^{87}Sr/^{86}Sr$ isotope analysis in Northern Chile

Previous work on oxygen and strontium isotopes has been undertaken in the area of the Atacama Oases. This research has mainly focused on the study of the Middle Period (AD 400-900) (Knudson, 2007; Knudson and Price, 2007; Nado et al., 2012; Knudson and Torres-Rouff, 2014). Knudson and colleagues, following a very similar pattern to Murra's theory for the LIP, have tried to look for foreign people from the Tiwanaku religious state in the cemeteries of the Atacama Oases. So far, no $\delta^{18}O$ values have been associated with non-local individuals for the Atacama Oases during the Middle Period (Knudson and Price, 2007; Nado et al., 2012; Knudson et al., 2015). The $\delta^{18}O$ results for Atacama Oases individuals range from -7‰ to 0‰, in a sample of more than 100 individuals (Knudson and Price, 2007; Knudson, 2009; Knudson and Torres-Rouff, 2009; Nado et al., 2012; Knudson et al., 2015). These results contrast with the ones obtained for the Bolivian *altiplano* in which individuals tend to show $\delta^{18}O$ values below -10‰ (Knudson and Price, 2007; Knudson, 2009).

Strontium isotopes have been more successful on identifying non-local individuals in the Atacama Oases. However, the number of outliers found at the cemeteries is low (Knudson 2007; Knudson and Price 2007; Nado et al., 2012). Only in one cemetery (Larache) more than one "non-local" individual (4 out of 48) (Knudson and Torres-Rouff, 2014) has been found, based on strontium isotopes. However, the origins of these non-local individuals remain in doubt.

The bioavailable strontium values for northern Chile as well as for Bolivia and northwest Argentina are poorly known. In the case of northern Chile, Knudson and Price (2007) produced a baseline for the Atacama Oases area using only three small mammals, with values between 0.7074-0.7079. For Bolivia, eight small mammals were considered for reconstructing the bioavailable strontium in the Lake Titicaca Basin

(northern *altiplano*) with a range of values of 0.7083-0.7110 (Knudson and Price, 2007). Apart from this information, no more bioavailable values for strontium have been published so far in the South Central Andes. Clearly a more robust bioavailable strontium isotope map for northern Chile is required.

Regarding mobility studies on the LIP in northern Chile, Knudson and Torres-Rouff (2009) evaluated human mobility in the locality of Caspana in the Alto Loa region, using oxygen and strontium isotopes. The authors considered the same baseline mentioned before for San Pedro de Atacama, to identify possible outliers. Based on the results obtained, Knudson and Torres-Rouff concluded that all the individuals analysed in the study had a local origin, with the exception of one outlier that shows a value of 0.7096 for $^{87}Sr/^{86}Sr$. Oxygen isotopes presented an average of -3.9±0.6‰, considered local.

Oxygen isotope analysis carried out in the Pica 8 (Santana-Sagredo et al., 2015a) and Cementerio Oriente de Quillagua (Santana-Sagredo et al., 2015b) sites in the Tarapacá cultural area evidenced the presence of at least four outlier individuals in each cemetery. The values for most of the non-local individuals are below -10‰.

7.5. Materials and Methods

7.5.1 Samples and methodology for stable oxygen isotope analysis

A total of 62 teeth enamel and 67 bone apatite samples was analysed for oxygen isotopes. The samples analysed here are the same as those in Chapter 5. They are from sites associated with the Antofagasta coastal groups, the Atacama Culture, and the coast and inland Tarapacá Culture groups. Details on the samples and cultural association are presented in Appendix 7.1.

Bone apatite was pre-treated following the procedures outlined in Chapter 5 for carbon isotopes (following Smith 2005). The isotope analyses of oxygen (measured in duplicate) were carried out in the Stable Light Isotope Laboratory of the University of Cape Town, on a Finnigan MAT 252 mass spectrometer coupled to a Gas bench II. International standards NBS 18 and NBS 19 together with laboratory marble standards were used for calibrating the results. The precision for oxygen isotopes was estimated in 0.15‰.

The pre-treatment for tooth enamel is described in Chapter 5, following the protocols of Sponheimer (1999). The pre-treatment procedures were carried out in the Research Laboratory for Archaeology and the History of Art, University of Oxford. Samples were analysed in the Stable Light Isotope Laboratory of the University of Bradford. Oxygen isotopes were measured in a Thermo Finnigan Delta V Advantage mass spectrometer coupled to a Gasbench II. The international standards CO-1 and CO-8 together with Merck $CaCO_3$ were used for calibrating the results. Precision for the oxygen isotopes results was 0.1‰.

7.5.2 Samples and methodology for radiogenic strontium isotope analysis

A total of 69 samples from the two study areas of Atacama and Tarapacá were analysed for $^{87}Sr/^{86}Sr$ ratios. In each area, plants, animal and human samples were analysed. Only enamel samples (apart from hair for two animals) were considered for humans and animals. Bone samples were avoided because of their higher susceptibility to diagenetic contamination, with the exception of one camelid bone.

For the Atacama cultural area modern plant samples were collected from the Atacama Oases including areas next to San Pedro de Atacama and Toconao. All the modern plant samples came from altitudes around 2.450-2.800 masl. The archaeological animal and human samples were collected from the Instituto de Investigaciones

Arqueológicas y Museo R.P. Gustavo Le Paige. For the archaeological fauna, enamel and hair samples from camelids and a puma were considered (n=5). Human enamel samples were taken from the LIP sites Quitor 6 (n=10), Catarpe 1 (n=2) and Toconce (n=1).

Its worth noting that in this institution the sampling of human tissues for scientific analysis is restricted, because of the ethical issues related to the indigenous Atacameño communities that also work in the museum. Therefore, out of respect to the communities, only a small number of human samples were taken, with their authorization.

For the Tarapacá Culture archaeological samples were collected for plants, animals and humans. The plants were collected from the Instituto de Investigaciones Arqueológicas y Museo R.P. Gustavo Le Paige and the Museo Regional de Iquique. The plant samples come from Quillagua (n=2), La Huayca-Canchones (n=2), Pica-Quisma (n=1), and the Tarapacá (n=2) and Tana (n=2) ravines. Animal samples from two coastal archaeological sites were collected from the Museo Regional de Iquique, including only marine fauna (Bajo Molle; n=3) and a dog tooth (Iquique: n=1). Human samples from the coastal sites of Los Verdes (n=3) and Bajo Molle (n=2) were collected at the Museo Regional de Iquique, while samples from the cemetery of Pica 8 (n=18) were collected from the Departamento de Antropología of Universidad de Chile. Details concerning the type of sample collected from each cultural area are presented in Tables 7.2 (plant and animal samples) and 7.3 (human samples).

A total amount of 50 mg per plant and hair sample was ashed at 800ºC for analysis. Analytical procedures were carried out at the clean lab of the Department of Geological Sciences, University of Cape Town, South Africa. Ashed samples were digested in HNO_3 for 48 hours at 140 ºC in closed Teflon beakers. Enamel samples were cleaned

through air abrasion using aluminium oxide with a Swam Blaster^{TM} system, and then drilled. A total of 50 mg per sample was collected for analysis. Samples were then digested in concentrated HNO_3 for 1 hour at 140ºC in closed Teflon beakers. Ashed and enamel samples were then prepared for Sr column separation following the protocol described in Pin et al. (1994). Samples were then ultrasonicated for 30 minutes. Strontium samples were finally analysed as 200ppb 0.2% HNO3 solution. The strontium isotope analyses were performed on a Nu Instruments NuPlasma HR in the MC-ICP-MS facility, housed in the Department of Geological Sciences, University of Cape Town, South Africa. The reference standard used for ashed plants was NIST SRM987 (0.710255). For tooth enamel, the standard NM95 was used (0.708907±23; n=56). All the strontium data obtained was corrected for Rb interference.

7.5.3 Statistical analysis

Shapiro Wilk test was applied in order to evaluate normality for strontium and oxygen isotopes. Formal statistical testing was only carried out for oxygen isotopes. This was not applied to strontium isotopes because of the very small sample number when comparing the cultural groups.

Strontium isotope values obtained for plant and animal samples were used in order to create a local baseline. Based on this information, outliers for $^{87}Sr/^{86}Sr$ were evaluated using two standard deviations from the baseline mean.

When two groups were compared a Mann-Whitney Wilcoxon test was applied. Kruskal Wallis, Multiple Comparison Test after Kruskal Wallis and ANOVA tests were performed when comparing more than two groups. Both tests (Kruskal Wallis and ANOVA) were used at the same time, to double-check the results. All the statistical analyses were run in R: The R Project for Statistical Computing (2003).

7.6 Results

7.6.1 Oxygen isotope results

Descriptive statistics for each group are presented in Table 7.1. Raw results each individual can be found in Appendix 7.1. The higher means for $\delta^{18}O$ were reported for the Antofagasta and Atacama groups with -6.0±0.3‰ and -5.9±1.1‰ for enamel apatite and -1.4±0.6‰ and -3.9±1.0‰ for bone apatite, respectively. In contrast, the lowest values were reported for the Tarapacá Inland group with an average of -8.9±1.7‰ for enamel apatite and -6.4± 1.4‰ for bone apatite. All the $\delta^{18}O$ values are presented in boxplots divided by tissue analysed (Figures 7.1, 7.2 and 7.3). In some cases, there is a considerable space between the enamel and bone apatite values.

Cultural group	$\delta^{18}O$ enamel				$\delta^{18}O$ bone apatite			
	Mean	SD	Max	Min	Mean	SD	Max	Min
Antofagasta	-6.0	0.3	-5.8	-6.3	-1.4	0.6	-0.3	-2.0
Atacama	-5.9	1.1	-4.0	-8.1	-3.9	1.0	-2.2	-6.7
Tarapacá Coast	-7.6	1.1	-5.2	-9.5	-4.6	0.9	-5.8	-5.8
Tarapacá Inland	-8.9	1.7	-3.7	-12.2	-6.4	1.4	-4.1	-9.7

Table 7.1. Descriptive statistics for oxygen isotopes in tooth enamel and bone apatite divided by cultural group.

For enamel apatite, the Tarapacá Coast ($W=0.86$, $p<0.05$) and Atacama ($W=0.75$, $p<0.05$) groups did not present a normal distribution. In the case of bone apatite, the situation was the same with the Tarapacá Coast ($W=0.71$, $p<0.05$) and Atacama groups ($W=0.0263$, $p<0.05$) not showing normally distributed values.

No significant differences were reported when enamel and bone apatite values were intragroup compared by sex. Significant differences were observed when comparing the enamel $\delta^{18}O$ values for the Atacama and Tarapacá Coast groups (Kruskal Wallis,

chi-square=27.87, p<0.05; ANOVA, F-value=11.3, p<0.05) as well as the Tarapacá Inland and Coast groups (Kruska Wallis, chi-square=27.87, p<0,05; ANOVA, F-value=11.3, p<0.05).

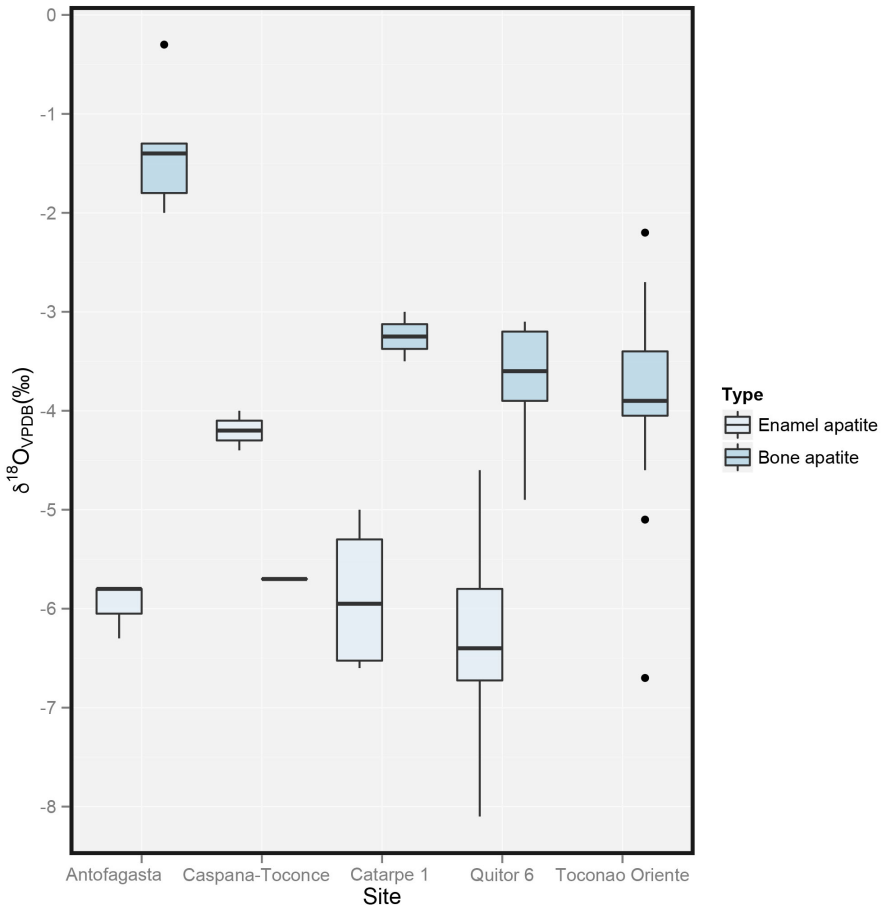


Figure 7.1. Boxplot showing oxygen isotope values for tooth enamel and bone apatite by site for the Antofagasta and Atacama-Alto Loa groups.

In the case of bone apatite, the situation changed showing significant differences between all the groups (Kruskal Wallis, chi-square=33.33, p<0.05; ANOVA, F-value=24.18, p<0.05) with the exception of the Atacama and Tarapacá Coast groups.

Tooth enamel and bone apatite present significant differences when compared by cultural group: Atacama (Mann-Whitney, W=59.5, P<0.05) Tarapacá Coast (Mann-Whitney, W=47, p<0.05) and Tarapacá Inland (Mann-Whitney W=55, p<0.05).

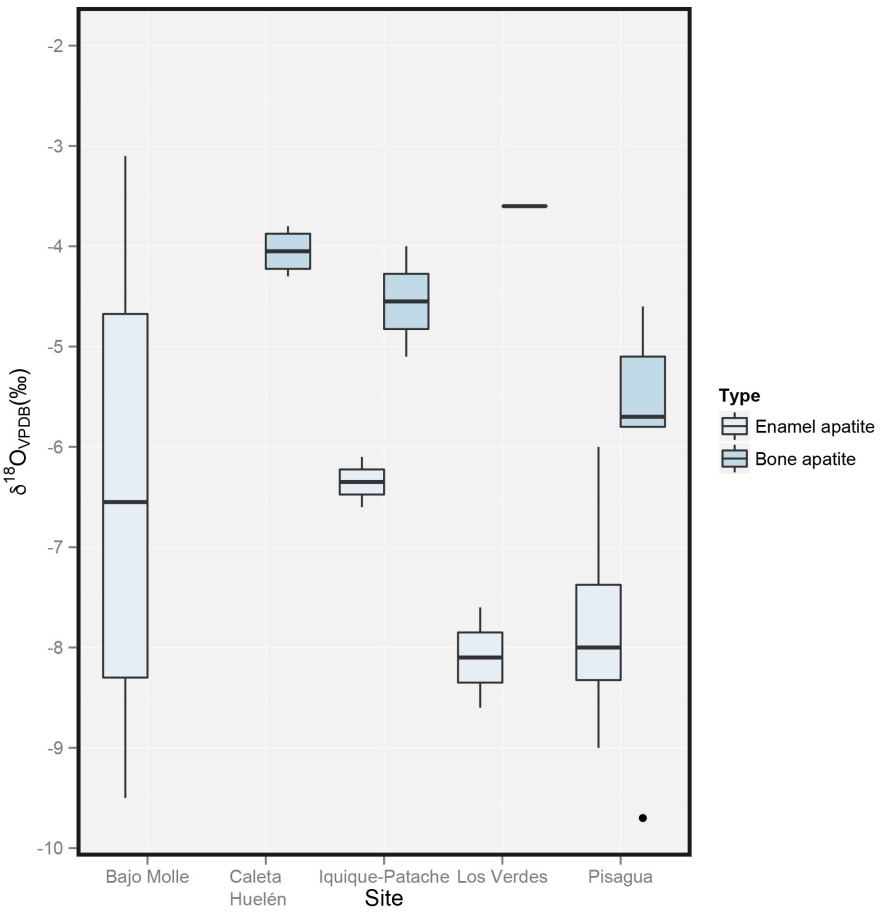


Figure 7.2. Boxplot showing oxygen isotope values for tooth enamel and bone apatite by site for the Tarapacá Coast groups.

7.6.2 Strontium isotopes in the Atacama-Alto Loa Cultural Area

Modern wild plant $^{87}Sr/^{86}Sr$ isotope ratios were obtained for a total of 13 samples (Table 7.2). The average is 0.7082± 0.0009. Values were normally distributed (W=0.85, p>0.05). These values were used for constructing a small local baseline for the Atacama Basin, based on 2σ. This gives a range of values of 0.7063-0.7101 (Figure 7.4).

Archaeological animals $^{87}Sr/^{86}Sr$ ratios (7.2) present an average of 0.7090 ± 0.0005 with a maximum of 0.7095 for the puma sample (*Puma concolor*) and a minimum of 0.7084 for the domesticated camelid bone sample. All of the values obtained for the

archaeological animal samples fall inside the local bioavailable Sr isotope range as defined by the wild plants.

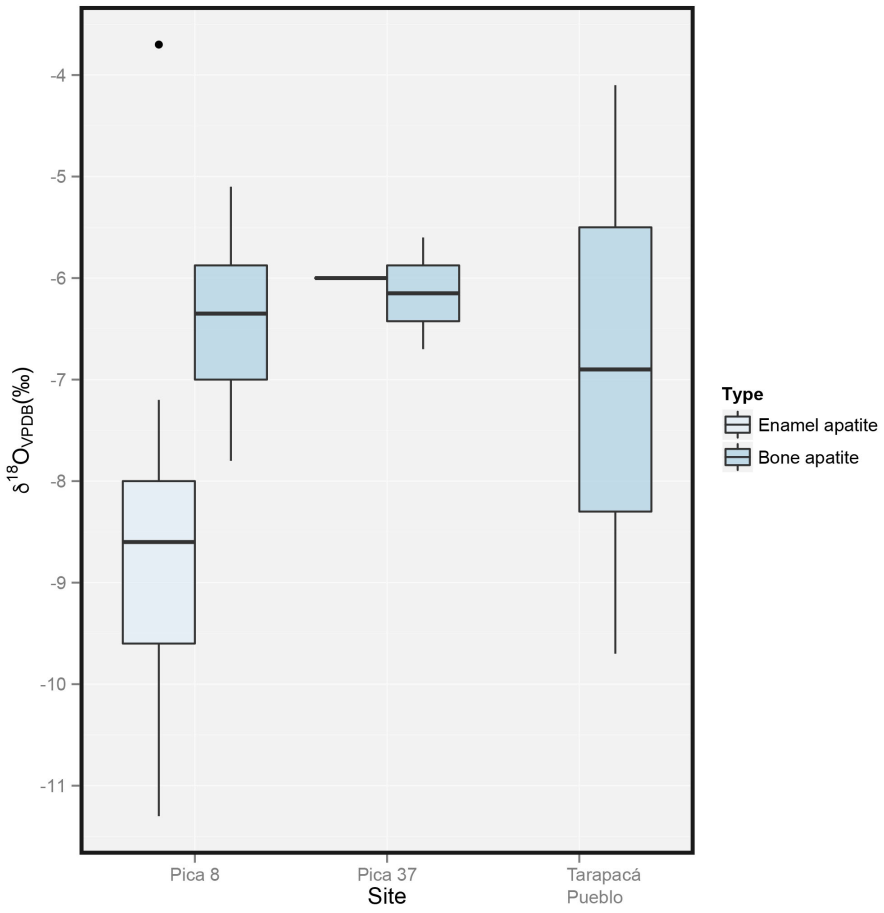


Figure 7.3. Boxplot showing oxygen isotope values for tooth enamel and bone apatite by site for the Tarapacá Inland groups.

For the archaeological human samples (Table 7.3), the average value for Quitor 6 is 0.7096 ± 0.0025 with maximum and minimum values of 0.7076 and 0.7143, respectively. The mean observed for male individuals (n=4) is 0.7100 ± 0.0024 while for female individuals (n=6) is 0.7093 ± 0.0028. Quitor 6 shows at least four individuals who fall outside the 'local' range (defined as 2σ generated from the modern plant values) (see Figure 7.4). Even at 3σ, the outliers are outside the local range with the exception of one individual that falls very close to the maximum $^{87}Sr/^{86}Sr$ value. Two of the outliers are male (T11, 0.7114; T35, 0.7127) while the other two are females (T07,

0.7108; T54, 0.7143). No outliers were observed for Catarpe 1, and for Toconce there was only one individual. However, more samples are needed to evaluate mobility for the populations of Catarpe 1 and Toconce.

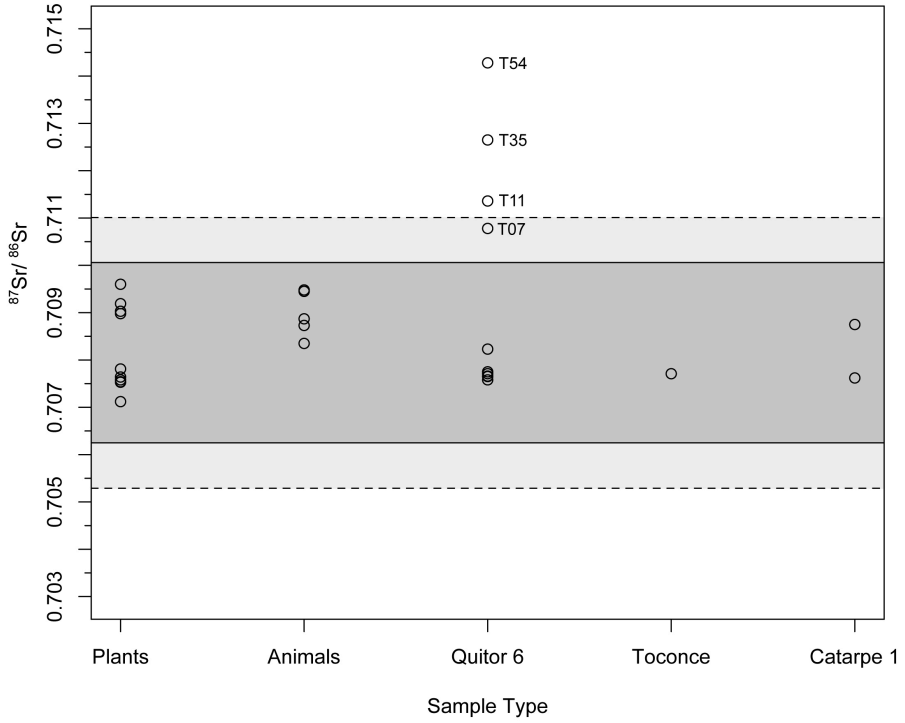


Figure 7.4. Plot showing the $^{87}Sr/^{86}Sr$ isotope ratios for plants, animals and human samples for the Atacama-Alto Loa cultural groups. Two standard deviations (2σ) $^{87}Sr/^{86}Sr$ ratio range (made on modern plant values) is shown in dark grey. Three standard deviations (3σ) $^{87}Sr/^{86}Sr$ ratio range (made on modern plant values) is shown in light grey.

7.6.3 Strontium isotopes in the Tarapacá Cultural Area

In contrast to the modern samples of the Atacama Oases, archaeological plant samples (Table 7.2) were analysed for Tarapacá (n=9). The average value for the plants is 0.7075 ± 0.0008. Values were normally distributed (W=0.74, p>0.05). A local bioavailable $^{87}Sr/^{86}Sr$ range using 2σ is proposed following these analyses (Figure 7.5) with values between 0.7065-0.7080. One plant sample fell outside this range, with a value of 0.7093 (highest of the 9 samples), and was excluded from the local bioavailable Sr values. This sample was taken from maize popcorn associated with the

Pica oases. The minimum value observed of 0.7068 for a maize sample comes from the site of Tana.

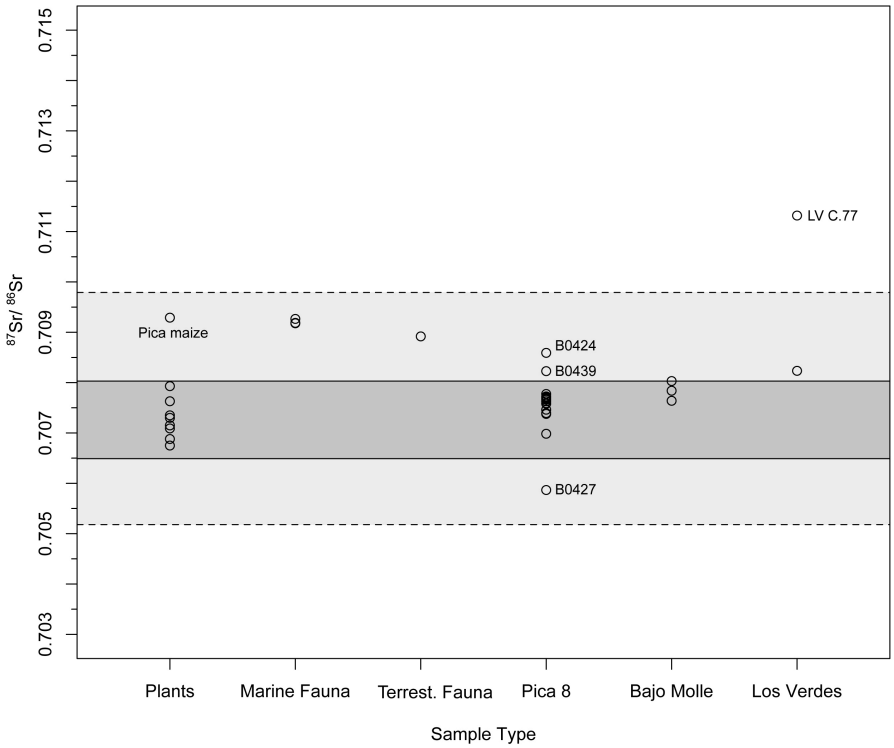


Figure 7.5. Plot showing the $^{87}Sr/^{86}Sr$ isotope ratios for plants, animals and human samples for the Tarapacá cultural groups, including the inland site Pica 8 and the coastal sites Bajo Molle and Los Verdes. Two standard deviations (2σ) $^{87}Sr/^{86}Sr$ ratio range (made on modern plant values) is shown in dark grey. Three standard deviations (3σ) $^{87}Sr/^{86}Sr$ ratio range (made on modern plant values) is shown in light grey

The fauna analysed for this area (Table 7.2) comes from the coastal sites of Bajo Molle and Iquique. As expected, the values for the fish and sea mammal samples have an average of 0.7092 ± 0.0004, closely matching the value of the modern ocean and are in agreement with the strontium isotopic ratios for marine ecosystems, (Veizer, 1989). The dog sample from Iquique shows a value of 0.70892 despite being from a coastal site.

Sample	Type	Species	Locality	Cultural Group	$^{87}/^{86}$Sr	±2s internal
Plant	Leaves	*Cortaderia atacamensis*	San Pedro de Atacama	Atacama	0.70758	13
Plant	Leaves	*Distichlis apicate*	San Pedro de Atacama	Atacama	0.70712	12
Plant	Leaves	*Poaceae sp*	San Pedro de Atacama	Atacama	0.70781	13
Plant	Leaves	*Tessaria absinthioides*	San Pedro de Atacama	Atacama	0.70753	14
Plant	Leaves	*Poaceae sp*	San Pedro de Atacama	Atacama	0.70898	13
Plant	Leaves	*Phragmites sp.*	San Pedro de Atacama	Atacama	0.70764	12
Plant	Leaves	*Atriplex atacamensis*	San Pedro de Atacama	Atacama	0.70753	14
Plant	Leaves	*Ephedra sp.*	Toconao	Atacama	0.70960	12
Plant	Leaves	*Cyperaceae sp.*	Toconao	Atacama	0.70919	12
Plant	Leaves	*Cyperaceae sp.*	Toconao	Atacama	0.70903	12
Animal	Tooth	NI/Domestic camelid	San Pedro de Atacama	Atacama	0.70945	14
Animal	Bone	NI/Domestic camelid	San Pedro de Atacama	Atacama	0.70835	14
Animal	Hair	*Lama glama*	San Pedro de Atacama	Atacama	0.70873	11
Animal	Hair	*Vicugna vicugna*	San Pedro de Atacama	Atacama	0.70887	13
Animal	Hair	*Puma concolor*	San Pedro de Atacama	Atacama	0.70948	12
Plant	Cob	*Zea mays*	Quillagua	Tarapacá	0.70715	14
Plant	Cob	*Zea mays*	Quillagua	Tarapacá	0.70735	13
Plant	Cob	*Zea mays*	Tana Sur	Tarapacá	0.70688	11
Plant	Cob	*Zea mays*	Tana Norte	Tarapacá	0.70675	12
Plant	Grains	*Prosopis sp.*	Tarapaca	Tarapacá	0.70763	13
Plant	Grains	*Prosopis sp.*	Tarapaca	Tarapacá	0.70793	12
Plant	Grains	*Prosopis tamarugo*	Canchones-La Huayca	Tarapacá	0.70709	18
Plant	Grains	*Geoffroea decorticans*	Canchones-La Huayca	Tarapacá	0.70730	13
Plant	Grains-pop corn	*Zea mays*	Pica-Quisma	Tarapacá	0.70929	15
Animal	Seal skin	*Otaria flavecescens*	Bajo Molle	Tarapacá	0.70926	11
Animal	Fish bone	NI	Bajo Molle	Tarapacá	0.70892	14
Animal	Fish teeth	NI	Bajo Molle	Tarapacá	0.70918	17
Animal	Dog	*Canis familiaris*	Iquique	Tarapacá	0.70919	13

Table 7.2. $^{87}Sr/^{86}Sr$ values for plants and animals of the Atacama and Tarapacá cultural groups.

The archaeological human samples (Table 7.3) come from two coastal sites and one inland site. Bajo Molle (n=3), south of Iquique in the coast, presents an average of 0.7078 ± 0.0002. At the coastal site of Los Verdes (n=2) individual LV1-C77 has a value of 0.7113, while individual LV1-C333 presents a ratio of 0.7082. It was not possible to sex these individuals.

Individual	Tooth Type	Site	Cultural Area	$^{87}Sr/^{86}Sr$	±2s internal
T07	3UM	Quitor 6	Atacama	0.71078	14
T11	2LM	Quitor 6	Atacama	0.71136	14
T30	3LM	Quitor 6	Atacama	0.70758	10
T31	3LM	Quitor 6	Atacama	0.70771	11
T34	2UM	Quitor 6	Atacama	0.70766	14
T35	2LM	Quitor 6	Atacama	0.71265	12
T40	3LM	Quitor 6	Atacama	0.70775	14
T47	3LM	Quitor 6	Atacama	0.70765	9
T51	3LM	Quitor 6	Atacama	0.70823	11
T54	2LM	Quitor 6	Atacama	0.71428	14
12.073	3UM	Toconce	Atacama	0.70771	12
C4849	2UM	Catarpe 1	Atacama	0.70875	13
C2396	3UM	Catarpe 1	Atacama	0.70762	12
B0413	2LPM	Pica	Tarapacá Inland	0.70769	16
B0419	2LM	Pica	Tarapacá Inland	0.70758	14
B0420	3UM	Pica	Tarapacá Inland	0.70770	13
B0421	3LM	Pica	Tarapacá Inland	0.70773	12
B0424	2UM	Pica	Tarapacá Inland	0.70859	16
B0426	2LM	Pica	Tarapacá Inland	0.70767	14
B0427	2UM	Pica	Tarapacá Inland	0.70587	13
B0428	3UM	Pica	Tarapacá Inland	0.70739	15
B0431	3UM	Pica	Tarapacá Inland	0.70738	14
B0432	3UM	Pica	Tarapacá Inland	0.70767	13
B0439	3UM	Pica	Tarapacá Inland	0.70823	10
B0440	2UPM	Pica	Tarapacá Inland	0.70772	13
B0447	2UM	Pica	Tarapacá Inland	0.70759	13
B0453	3UM	Pica	Tarapacá Inland	0.70698	12
B0463	3UM	Pica	Tarapacá Inland	0.70766	13
B0468	2UM	Pica	Tarapacá Inland	0.70746	14
B0483	3LM	Pica	Tarapacá Inland	0.70777	11
B0493	2LM	Pica	Tarapacá Inland	0.70763	13
BM.1S5 153	3UM	Bajo Molle	Tarapacá Coast	0.70803	14
C.189	2UM	Bajo Molle	Tarapacá Coast	0.70764	14
C.151	2LPM	Bajo Molle	Tarapacá Coast	0.70784	15
C.333	1LPM	Los Verdes	Tarapacá Coast	0.70823	12
LV-1 C.77	2UPM	Los Verdes	Tarapacá Coast	0.71132	12

Table 7.3. $^{87}Sr/^{86}Sr$ values for human tooth enamel samples from the Atacama-Alto Loa and Tarapacá Inland and Coast cultural groups, where: 1LPM= First lower premolar, 2LPM= Second lower premolar, 2UPM= Second upper premolar, 2UM= Secon upper molar, 2LM=Second lower molar, 3UM= Third upper molar, 3LM= Third lower molar.

The $^{87}Sr/^{86}Sr$ isotopic ratios for the Pica 8 cemetery (n=18) show a mean of 0.7076 ± 0.0005 with maximum and minimum values of 0.7086 and 0.7059, respectively. When comparing the Pica 8 values with the 2σ local ranges for Tarapacá, at least three

outliers (B0424, 0.7086; B0427, 0.7059; B0439, 0.7082) can be recognized (Figure 7.5), of which two are female (B0424 and B0439) and one male (B0427). The mean observed for male individuals (n=5) is 0.7072 ± 0.0008 while for female individuals (n=13) the average is 0.7077 ± 0.0004.

7.7 Discussion of oxygen isotope results

The results show variability in the values by cultural group, which was expected bearing in mind the complex hydrology characterising the Atacama Desert.

The range of values observed for the Atacama Inland groups are comparable to those previously reported by Knudson et al. (2009) and Nado et al., (2012) for the Atacama Oases. Their results show that the human oxygen isotope in the area ranges from approximately -7‰ to -0‰. This is not surprising because, during a single year the $\delta^{18}O$ values from the San Pedro and Vilama rivers, located in the Atacama Oases, can vary in about 4‰ (Aravena, 2013 Pers. comm). As discussed in Chapter 2, the high evaporation rates occurring the Atacama together with the complex groundwater system coming from the Andes lead to great variability of the oxygen isotope composition in meteoric waters (Magaritz et al., 1990; Aravena, 1995; Aravena et al., 1999).

Most of the results obtained for the Atacama-Alto Loa group here, show values that fall in the range expected for the oases (Boschetti et al, 2007; Knudson, 2009; Nado et al., 2012; Knudson et al., 2015). However, Quitor 6 burials T11 and T54 present lower values of -7.3‰ and -8.1‰ for their tooth enamel, respectively. These two values are below the range for the Atacama Oases, suggesting the ingestion of more depleted waters in ^{18}O.

The Antofagasta coastal groups show the most enriched in ^{18}O composition for the entire suite of samples. As they are located next to the coast, it is probably they had access to springs or accumulations of fog water with high $\delta^{18}O$, under high evaporation rates (Aravena, 1995, Aravena et al., 1999). Unfortunately, there is no information available on the oxygen isotope composition of springs/fog from this area in northern Chile. Their values, however, do resemble those observed for the Atacama Oases (Knudson et al., 2009; Nado et al., 2012; Knudson et al., 2015). Therefore, it would seem to be impossible to differentiate between an individual from the Antofagasta coast compared to the Atacama Oases based on $\delta^{18}O$ alone.

On the other hand, the Tarapacá cultural groups both from coast and inland have lower $\delta^{18}O$ values, compared to individuals from Atacama and Antofagasta. As noted in Chapter 2, groundwater systems of *Pampa del Tamarugal* carry water directly from the mountains, and coming up to surface forming springs and oases (Magaritz et al., 1990; Aravena, 1995). This causes low $\delta^{18}O$ values for the spring water compostion (Magaritz et al. 1990). The Pica oases, for instance, present the lowest $\delta^{18}O$ values in their water composition compared to other Pampa del Tamarugal water sources (Aravena, 1995). The oxygen isotope results obtained for tooth enamel and bone apatite for Tarapacá inland follows this pattern of depleted ^{18}O. This has been reported before for human bone apatite of the Pica 8 cemetery with most values ranging between -6‰ to -9‰ (Santana-Sagredo et al., 2015a). A similar situation occurs by the Tarapacá coast. This is not surprising because the groundwater system reaches the coast forming small springs. Without these springs, human occupation of the coast would have not been possible.

Nevertheless, there are outlier individuals amongst the Tarapacá Inland group. For example, individual B0424 from Pica 8 exhibits a considerably low $\delta^{18}O$ value (tooth enamel, -3.7‰). A previous study on bone apatite for Pica 8 suggests that the local

individual values would only have ranged between -6‰ and -9‰ (Santana-Sagredo et al., 2015a). Here, four individuals' tooth enamel presented very depleted ^{18}O composition with values of -11.3‰ (individual B0420); -10.9‰ (individual B0427); -11.0‰ (individual B0453); and -11.0‰ (individual B0476), suggesting a non-local origin. Such low values have only been observed for *altiplano* groups of the Titicaca Basin (Knudson, 2009). It is not intended to propose here that these individuals came from the Titicaca Basin, but it is probable they originated from somewhere high in the *altiplano*. Values below -9‰ have not been reported so far, for local inland and coastal populations in northern Chile (Knudson, 2009; Nado et al., 2012; Ballester and Clarot, 2014; Knudson et al., 2015, Pestle et al., 2015; Santana-Sagredo et al., 2015a; Santana-Sagredo et al., 2015b).

Bone and enamel apatite present significant differences for each of the cultural groups analysed here, being the second ones more enriched in ^{18}O. However, the values for both tissues are still in the "local" range expected for each area, compared to the meteoric water values (Aravena, 1995; Aravena et al., 1999; Boschetti et al., 2007) and the previous results obtained on human bone and enamel by Knudson 2009, Nado et al., 2012 and Knudson et al., 2015. It is not clear if these differences could be providing information about the variation in oxygen isotope composition of water during pre-Columbine moments in the past; or if these could be associated with unknown physiological or cultural reasons. Further research is needed in order to better understand the variability of oxygen isotopes in the Atacama Desert. It is clear by the results obtained here and in previous research that this technique cannot be used to differentiate between inland and coastal populations, but rather coast-inland versus *altiplano* values.

7.8 Local Bioavailable Sr values for the Atacama Oases: implications for mobility studies

Based on the results obtained a new bioavailable $^{87}Sr/^{86}Sr$ baseline is presented for the Atacama Oases showing values between 0.7063-0.7101 (2σ range). The highest values observed for the modern plant samples come from the species *Ephedra* sp. (0.7096) and *Cyperaceae* sp. (0.7090; 0.7092) collected from the town of Toconao (30 km away San Pedro de Atacama), specifically from the Jérez ravine, where the Toconao River flows. This is not unexpected, since strontium isotope analysis has been done on the surface and groundwaters of the Atacama salt lake, including the rivers next to the Atacama Oases (Ortiz et al., 2013): the San Pedro river, next to San Pedro de Atacama and the Toconao River next to Toconao (Figure 7.6). For the Toconao River, an $^{87}Sr/^{86}Sr$ value of 0.7091 was obtained while that for the San Pedro River was 0.7076 (similar to the value obtained by Boschetti et al. [2007] for the same river). The $^{87}Sr/^{86}Sr$ values for the Toconao modern plants are thus in agreement with the values from the river water. Similarly, the values for the other plants from the Atacama Oases ($^{87}Sr/^{86}Sr$ values ca. 0.707), coming specifically from the town of San Pedro de Atacama are also comparable to the values of the San Pedro River. The study done by Ortiz et al. (2013) shows significant variability in the $^{87}Sr/^{86}Sr$ ratios for the waters of the Atacama salt lake, which receives all the rivers water and groundwater of the area. The range of values for the Atacama salt lake and its associated rivers lie between 0.7076 and 0.7113 (Ortiz et al., 2013). The high $^{87}Sr/^{86}Sr$ ratios (above 0.710) are mainly observed for the salt lake itself (Figure 7.6). It is highly unlikely that humans had consumed the plants growing in the salt lake in the past, since none of these plants are edible, nor would it be suitable for irrigating crops. For this reason, it is preferable to consider the plants growing next to the oases where people had access to fresh water and edible resources.

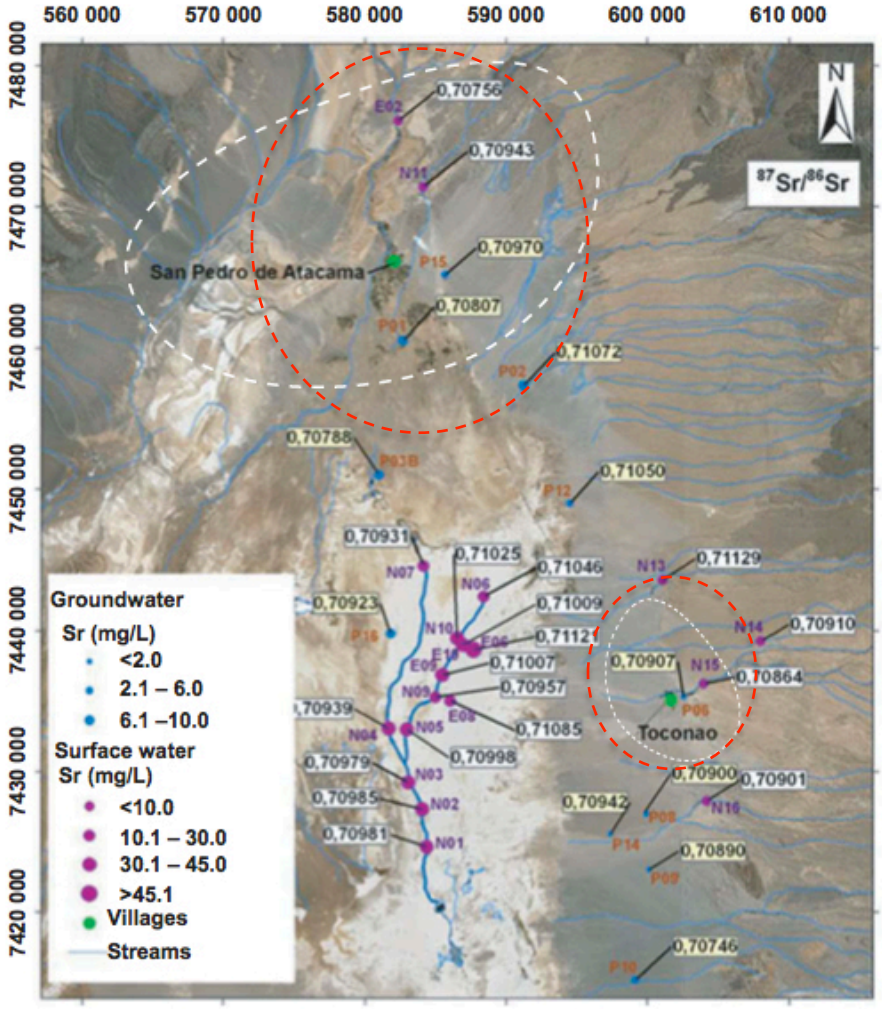


Figure 7.6. Modified map (Ortiz et al. (2013) of $^{87}Sr/^{86}Sr$ isotope ratios in surface and groundwater from the Atacama Oases and Salt Lake. Surface water values for San Pedro de Atacama and Toconao are indicated by dotted ellipses. Coordinates are shown in UTM.

Strontium isotope ratios for modern plants obtained in this research together with rock values from previously published work (Godoy et al., 2014; Mamani et al., 2010) obtained from the volcanoes of the surrounding region are presented in Figure 7.7. Values for volcanoes from northern Chile, Bolivia and northwestern Argentina are shown. For the Atacama-Alto Loa Cultural region (represented by square symbols), the values clearly fall between 0.7070-0.7099, while the volcanoes of the surrounding Andes, next to the Atacama Oases show a wider range from 0.7040 up to 0.7080. Since the Andes are relatively new in terms of geological time, with expected low $^{87}Sr/^{86}Sr$ values of ca. 0.704, the higher values observed for the volcanoes of the

region have been interpreted as the influence of crustal contamination (Godoy et al., 2014). Crustal contamination occurs during volcanic eruptions, as magma crosses a very thick crust in the Andes of 70 km thick, bringing with it high values >0.706 from old buried rock (Godoy et al., 2014). The ignimbrite rocks present in the Andes surrounding the Atacama-Alto Loa region shows this crustal contamination effect (e.g. Sairecabur, Licancabur and Lascar volcanoes, Mamani et al., 2010).

All this variation, that it is also not uniform across the Andes, is an important factor to consider when analysing radiogenic strontium isotopes for mobility and provenance studies. Northern Chile's geology shows a very complex composition, necessitating the construction of a proper bioavailable Sr isotope map for this area.

The archaeological animal samples collected from the area also show values within the local range, although being characterized for having a considerable range of mobility in the Andes. One of the samples derives from a puma (*Puma concolor*), an animal that usually lives between 3000 and 4200 masl, moving along a wide, high corridor in the Andes. The other samples came from domesticated camelids (probably llamas) and one vicuña (*Vicugna vicugna*). Domesticated camelids are known graze over a large range, between altitudes of 2450-4200 masl. It is also probable that llamas were used for caravan activities or mobility between different regions, so are not a good indicator for reconstructing locally bioavailable strontium. A similar situation happens with vicuñas. These wild animals do not go below 3000 masl and are quite mobile in different areas of the Andes, reaching areas up to 4200 masl.

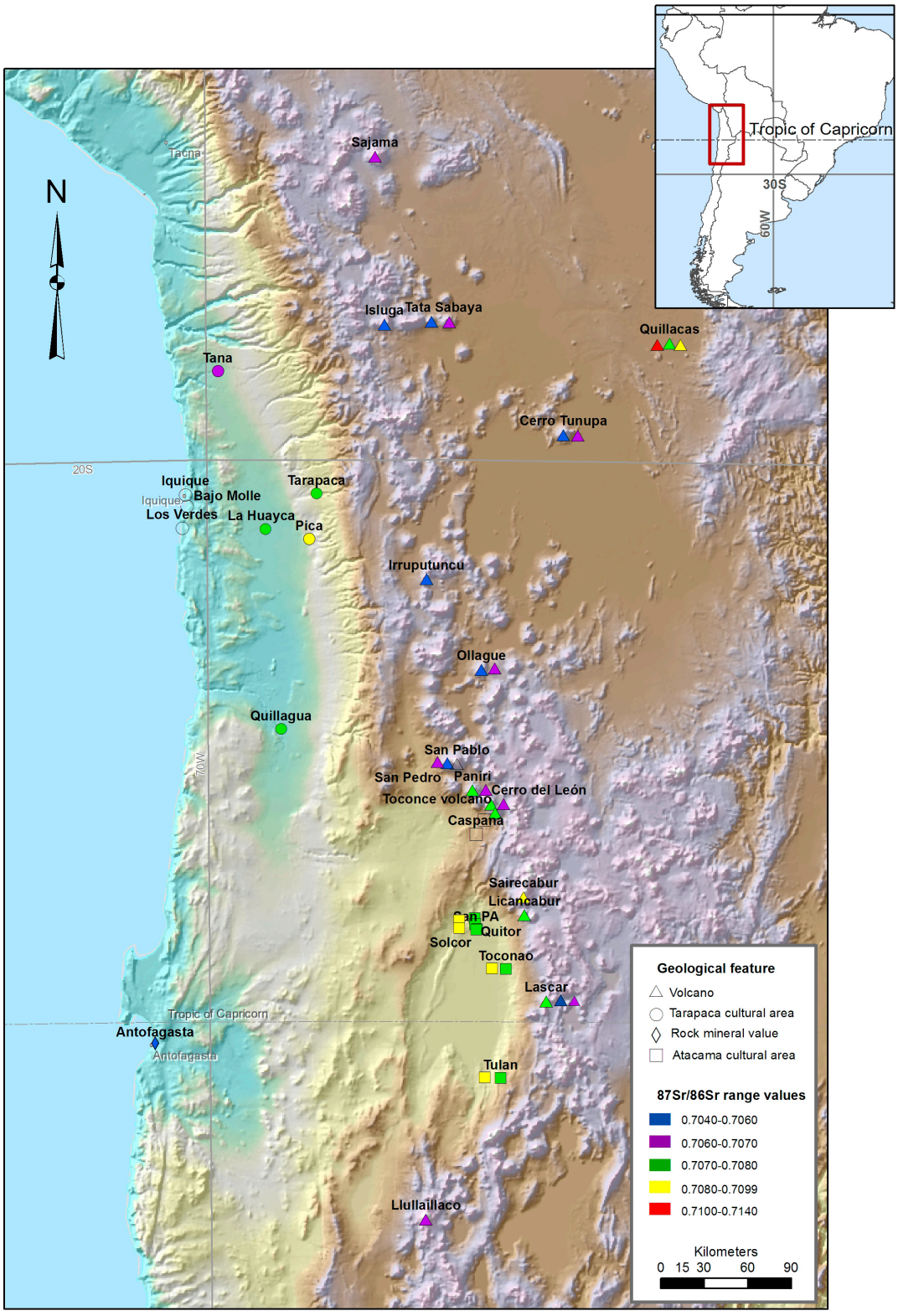


Figure 7.7 $^{87}Sr/^{86}Sr$ distribution map from northern Chile and Bolivian *Altiplano*. Plant samples are represented by circle symbols for Tarapacá and square symbols for Atacama. Volcanoes are represented by triangles. Different colours detailed in the legend represent the $^{87}Sr/^{86}Sr$ range of values. Volcanoes $^{87}Sr/^{86}Sr$ values were obtained from Davidson and de Silva (1995), Mamani et al. (2010), Godoy et al. (2014).

Regarding the human individuals analysed for the Quitor 6, Catarpe 1 and Toconce cemeteries, the evidence suggests that most had a local origin, with the exception of four individuals from Quitor 6. Unfortunately, in the absence of bioavailable strontium data for the area (including Bolivia and the northwestern Argentina) it is very difficult to associate these outliers with a specific locality. The only available values that actually match the Quitor 6 outliers come from the *Altiplano* of Bolivia. These values were obtained from rocks of the Quillacas area (Davidson and de Silva, 1995) (Fig. 5) next to Lake Poopó, and are between 0.7100-0.7140. Water from lake Poopó has also been analysed for $^{87}Sr/^{86}Sr$ ratios showing a range of 0.7140-0.7184 (Groove et al., 2003; Placzek et al., 2011). However, further information is needed in order to suggest a provenance origin for the Quitor 6 outliers.

7.9 $^{87}Sr/^{86}Sr$ isotope ratios in the Tarapacá cultural region

For the Tarapacá cultural groups, the baseline built on archaeological plant values has a range of $^{87}Sr/^{86}Sr$ between 0.7065-0.7080. The range, compared to that of the Atacama-Alto Loa Cultural Area, presents lower $^{87}Sr/^{86}Sr$ isotope ratios. With the exception of the localities of Tana and Pica-Quisma, La Huayca-Canchones, Tarapacá and Quillagua show very similar and consistent values around 0.707 and 0.708. The plant values contrast with the rock values from the surrounding volcanoes of the South Central Andes, showing lower values around 0.7040-0.7060 in most cases (Figure 7.7).

Only one plant sample (maize popcorn and grains homogenised) from Pica-Quisma had an outlier value of 0.70929 (falling outside the 2σ for the plants analysed) (Figure 7.5). It is possible that this crop could have come from somewhere else or that the use of manure could have affected its values. The $\delta^{13}C$ and $\delta^{15}N$ values for this sample are

-9.7± 0.2‰ and 7.4 ± 1.9‰, respectively. Since the values for $\delta^{15}N$ are not as high as other crops that evidence fertilizers use (Szpak et al., 2012), it is more likely that this maize sample could have come from another geological region.

All the plant samples come from inland sites, so the local baseline built for this cultural area must be considered only for the valley sites and not the coast. It is necessary to include plant samples from the coast for future analyses. Coastal geological features are quite different to those inland, with much older lithologies dating to the Cretaceous Period, but also with the presence of more recent sediments (SERNAGEOMIN).

Archaeological animal values for marine fauna are in agreement with the $^{87}Sr/^{86}Sr$ isotope ratios expected for the sea (0.7092) (Veizer, 1989). However, they clearly fall outside the local range made from the plant values. A dog recovered from the Iquique coast gave a value of 0.7089.

Archaeological humans from the coastal sites of Bajo Molle and Los Verdes differ from each other. Bajo Molle individuals present $^{87}Sr/^{86}Sr$ isotope ratios similar to those observed for the inland baseline, showing values between 0.7076 and 0.7080. In contrast, Los Verdes has higher $^{87}Sr/^{86}Sr$ values. In fact, one individual from Los Verdes can be clearly considered as an outlier (LV. C77; 0.7113). As with the outlier individuals from Quitor 6, it is very difficult to predict the provenance of individual LV. C77, also because there is no information about the bioavailable Sr values from the coast and its surrounding areas. Again, the most similar values to this individual are observed in the lithologies of the *Altiplano* of Bolivia, as well as the Titicaca Basin. But it would not be appropriate to associate this individual with a local origin in Bolivia considering the lack of radiogenic strontium isotopes in the area.

7.10 What do $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values in combination tell us about mobility during the LIP?

From the analysis carried out here including strontium and oxygen isotopes, at least four outlier individuals were recognised for the Atacama-Alto Loa Cultural group and five for the Tarapacá Culture. It is striking that some of the outliers for strontium isotopes are the same as for the oxygen isotopes, reinforcing their identification as potential migrants.

In the Atacama-Alto Loa Cultural group, the Quitor 6 cemetery shows that individuals T07, T11, T35 and T54 are outliers for their $^{87}Sr/^{86}Sr$ ratios. At the same time, individuals T11 and T54 show $\delta^{18}O$ values that fall outside the range expected for the Atacama Oases (Knudson, 2009; Nado et al., 2012; Knudson et al., 2015). Figure 7.8 shows a bivariate plot for $^{87}Sr/^{86}Sr$ ratios and $\delta^{18}O$ values of tooth enamel, in which these two outlier individuals can be clearly identified. Individuals T07 and T35 on the other hand, are outliers only for strontium, showing local values for oxygen isotopes.

This evidence would strongly suggest a different origin for at least three of these individuals. Individual T54 presents the highest $^{87}Sr/^{86}Sr$ as well as lowest $\delta^{18}O$ values. Even though the $^{87}Sr/^{86}Sr$ ratio could indicate a possible origin in the *altiplano* the oxygen isotope values are not sufficiently depleted in ^{18}O to support this origin. In addition, this individual was already mentioned in Chapter 5 as showing the highest $\delta^{13}C$ value. This aspect also goes against a possible origin in the *altiplano*, following its heavy reliance on maize. Different origins could be suggested for this individual in particular, including northwestern Argentina or the eastern valleys of Bolivia, almost reaching the Amazon. However insufficient strontium and oxygen isotope data is available from these areas. For this reason, the origin of this female individual remains unknown. As discussed in Chapter 5, this individual was buried with evidence

associated with mobility and the use of llamas for carrying objects (hook for attaching sacks on camelids).

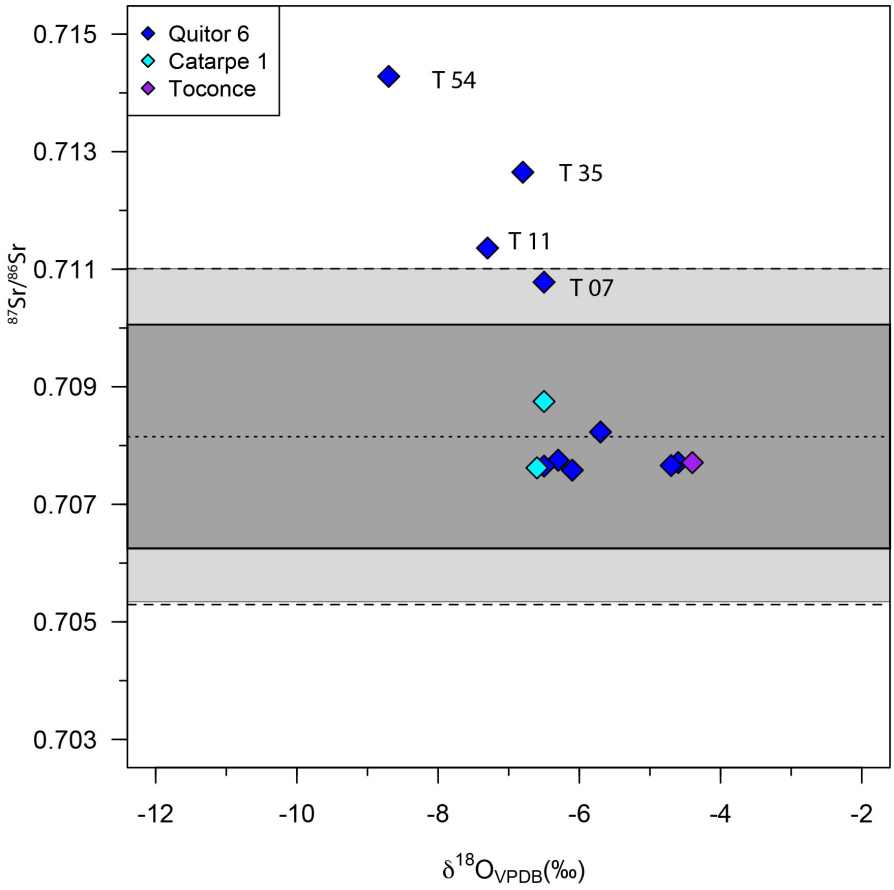


Figure 7.8. Bivariate plot showing $\delta^{18}O$ values and $^{87}Sr/^{86}Sr$ ratios for human enamel of the Atacama-Alto Loa sites Quitor 6, Catarpe 1, Toconce. Two standard deviations (2σ) $^{87}Sr/^{86}Sr$ ratio (modern plant values) range is shown in dark grey. Three standard deviations (3σ) $^{87}Sr/^{86}Sr$ ratio range (modern plant values) is shown in light grey.

Individuals T07, T11 and T35 presented carbon isotope values that are quite similar to the local populations, suggesting similar dietary patterns to the Quitor 6 individuals during their childhood, even though they came from different places. For the Tarapacá group previously seen and "new" outliers were recognised, for strontium and oxygen isotopes in tooth enamel. As shown in Figure 7.9, individuals B0420, B0427, and B0453 from the Pica 8 cemetery are clear outliers, being quite depleted in ^{18}O. Only individual B0427 shows a different $^{87}Sr/^{86}Sr$ ratio, falling almost outside the local range (considering 2σ). These three individuals also presented the most low $\delta^{13}C$ values for tooth enamel in Pica 8. Two individuals, B0420 and B0453, changed their diets late in

their lives, contrasting with individual B0427 that retained the original diet until the months before his death. These three individuals show oxygen isotope compositions similar to those reported for the Bolivian *altiplano* (Knudson, 2009). In addition the three consumed little if any C_4 resources during their childhood, instead displaying a diet based on C_3 resources, presumably including *quínoa* and potatoes. However, for individuals B0420 and B0453 strontium isotopes are quite similar to those from Pica 8. This evidence suggests origins for these three individuals in different locations of the *altiplano*.

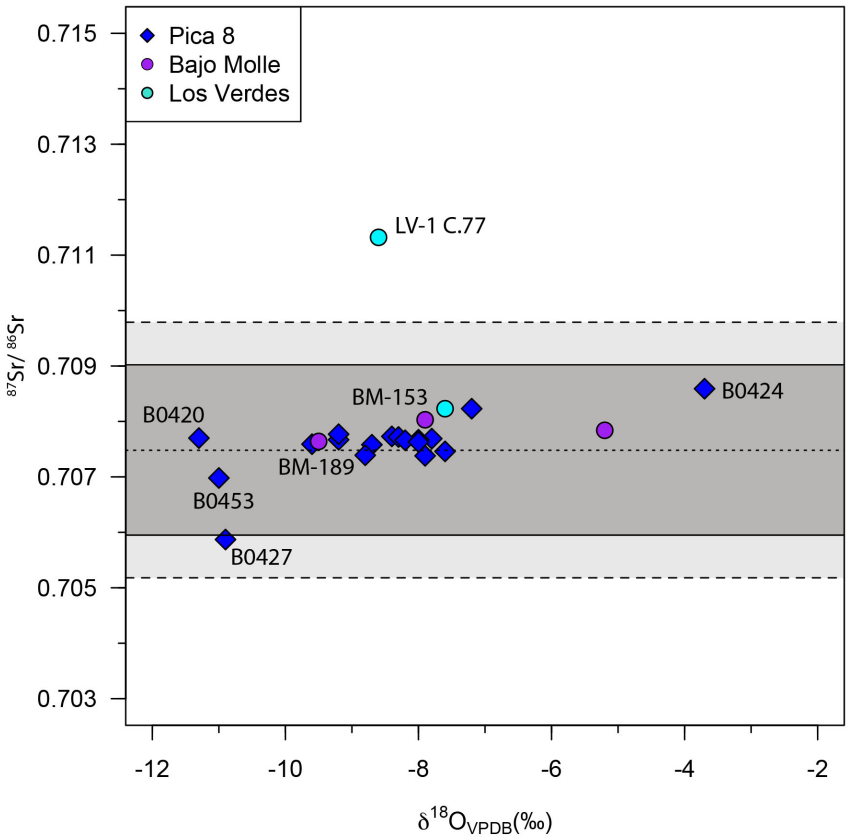


Figure 7.9. Bivariate plot showing $\delta^{18}O$ values and $^{87}Sr/^{86}Sr$ ratios for human enamel of the Tarapacá sites Pica 8 (inland) Los Verdes 1 and Bajo Molle (Coast). Two standard deviations (2σ) $^{87}Sr/^{86}Sr$ ratio (modern plant values) range is shown in dark grey. Three standard deviations (3σ) $^{87}Sr/^{86}Sr$ ratio range (modern plant values) is shown in light grey.

Individual B0424 is radically different to individuals B0420, B0427 and B0453, with values high in $\delta^{18}O$. Nevertheless, its $^{87}Sr/^{86}Sr$ ratios are consistent with the local Tarapacá values. This individual presented the highest $\delta^{15}N$ values observed for bone collagen (Santana-Sagredo et al., 2015a) and hair keratin (Chapter 5) of all the Pica 8 individuals. It is not possible to associate these individuals with a specific geological area, although its stable carbon and nitrogen isotopes (the latter in the case of individual B0424) could point to a coastal origin. However, the oxygen isotope values obtained for coastal Tarapacá are quite depleted in ^{18}O in most cases, looking quite similar to those of Pica 8. In this sense, its oxygen isotopic composition could be associated with the Antofagasta values, or other coastal areas that have not been studied as yet, such as the Arica region.

For the Tarapacá Coast group, one clear outlier was identified at the site of Los Verdes 1. This individual shows $^{87}Sr/^{86}Sr$ ratios that resemble those observed for Quitor 6 outlier individuals (Figures 7.8 and 7.9). None of the Pica 8 outliers show high strontium ratios. However, their oxygen isotopes look quite "local" to the Tarapacá Cultural region (including valleys and coast). Unfortunately, no information is available for the carbon and nitrogen isotope composition of this individual from either bone collagen or hair keratin. Nevertheless, its carbon apatite value (-8‰) could be suggesting either a mixed C_3-C_4 diet or a marine protein input. However, without the nitrogen isotope information, it is difficult to make any conclusions about this individual.

Individual BM-189, from Bajo Molle Edificio Armada, plots very close to the Pica 8 group. In Chapter 5, this individual was described as a clear inland individual that died by the coast. In fact, this individual did not change its diet while being at the coast, retaining the local inland Pica 8 composition. For this reason, it is remarkable to observe its strontium and oxygen isotope compositions being so similar to those of Pica 8. This evidence supports even more strongly the hypothesis this was an inland

individual that travelled to the coast. A similar situation occurs with individual BM-153. However, in this case the diet did change during the last months of life to a one very marine-based, as discussed in Chapter 5. It needs to be recalled that the values presented in Figure 7.9 reflect childhood origins.

As discussed in Chapter 5 there is considerable individual diversity in dietary patterns in the Atacama Desert during the LIP. The mobility patterns are associated with this observed variability in diet. Strontium and oxygen isotopes strongly support individual mobility to the Atacama Oases, as well as to the Tarapacá valleys and coast. Male and female individuals would have travelled to and died at these sites, changing their diets to the local traditions in some cases while retaining aspects of their original style of dress.

It is remarkable that the $^{87}Sr/^{86}Sr$ ratios as well as $\delta^{18}O$ values suggest different geographic and geological origins for most individuals. There are no patterns in the values observed. At the same time, the evidence presented here does not support the idea of a colonial presence in the lowlands. Instead, mobility appears to have happened at the individual level, or in small groups, in different directions and from different origins. From the results obtained here, it is suggested that people from the altiplano, coast, and probably northwest Argentina and the eastern valleys of the Andes were travelling to the Atacama and Tarapacá Oases. This included mobility of females and males, at different moments of their lives. So, the possibility of very specialised pastoralist groups from the highlands moving around the desert in llama caravans remains questionable.

7.11 Conclusions

This chapter presented a first approach in the reconstruction of a local bioavailable strontium baseline for the Atacama-Alto Loa and Tarapacá Cultural regions. This information is important considering the almost complete lack of bioavailable strontium data for northern Chile, the Bolivian *altiplano* and northwest Argentina. Without such data it is difficult to study human mobility and provenance in the area. Since one of the main aims of this thesis is to better understand human mobility patterns during the Late Intermediate Period, it is essential to have a proper local $^{87}Sr/^{86}Sr$ baseline. It is also necessary to complement this information with other stable isotopes such as carbon, nitrogen and oxygen. As presented previously, the use of multiple isotopes can lead to more accurate interpretations concerning the possible provenance of non-local individuals.

It has been shown that northern Chile's geology is quite complex and $^{87}Sr/^{86}Sr$ ratios in ancient human remains cannot be interpreted in a straightforward manner, certainly not with the use of $^{87}Sr/^{86}Sr$ isotope ratios in three small mammals to reconstruct the local baseline (Knudson and Price, 2007). Such a limited set of values can lead to serious problems in the interpretations of data, complicating even more the understanding of the Atacama Desert's prehistory. Even though this first approach to the application of $^{87}Sr/^{86}Sr$ ratios in northern Chile used a small amount of plants for reconstructing the bioavailable strontium distribution, it was possible to show the region's high variability. At the same time, in each cultural area different outlier individuals could be identified using the newly developed local 2σ baseline. However, future work needs to focus on the probable localities whence these individuals originated. New studies are also needed in the adjacent regions of Bolivia and Argentina, places from where the non-local individuals are likely to have orginated. In addition, stable oxygen isotope analysis

together with radiogenic strontium isotope analysis on human tooth enamel and bone strongly suggest mobility patterns during the LIP were quite diverse. People from different locations arrived to the Atacama Desert, probably individually or in small groups, but not in former colonies. Further research is need in order to understand how this mobility occurred and what was the driving force leading to the contacts and interactions between these populations (apart from the economic complementarity reasons).

Chapter 8

Discussion and Conclusions

In this final chapter, results and findings obtained throughout the thesis will be synthesised and reviewed in the light of the aims and objectives set out in Chapter 1. The two first sections will discuss the implications of the isotope results on the mobility models for the LIP a how to re-interpret mobility in northern Chile. In the third section, results obtained for the new local isotope baseline for northern Chile will be briefly discussed. Finally, the fourth section presents the conclusions of this thesis.

8.1. Re-thinking the Late Intermediate Period in northern Chile: New insights on mobility and dietary patterns

The main aim of this research has been to characterise the local diet and mobility patterns for northern Chile during the LIP, in order to test the hypotheses (1) about the presence of *altiplano colonies* in the lowlands; (2) and the validity of the "gyratory mobility" of Núñez and Dillehay (1995), in which mobility only happened through specialised pastoralist groups from the highlands-*altiplano*. Both 'dietary' and 'mobility' isotopes are brought to bear on these questions.

The isotopic evidence obtained here shows the presence of few non-local individuals that could be characterised as first generation immigrants in the Tarapacá and Atacama cultural areas. The most plausible explanation for these results is that there were no *altiplano* colonies in the lowlands of northern Chile, *contra* the colonisation models of Murra and the gyratory mobility model of Núñez and Dillehay (1995). These results are consistent with the lack of material evidence for colonies in the valleys and coast of northern Chile (Adán et al., 2004; Uribe, 2006). Equally, assuming that only

specialised agro-pastoralist groups were moving and controlling trade is too reductionist and not supported by the findings of this study. Mobility patterns were probably quite complex and different to what has been proposed so far. For example mobility could have occurred due to different reasons such as use of lands, kinship relationships, and also trade but this time controlled by both local and foreign peoples. The isotopes results on bone collagen and apatite as well as tooth enamel and hair keratin show that a diverse range of individuals was moving, including female and males at different moments of their lives. At the same time, some of these non-local individuals changed their diets to the "local menu" during their last years/months of life, while others did not.

Mobility patterns during the LIP, included people moving from the *altiplano*, the highlands, valleys, coast and probably other geographical regions. People did not have to be specialised pastoralists from the highlands in order to travel through the Atacama. A strong presence of camelids herds has been evidenced for the low valleys such as in the Caserones site, in which plenty of camelid corrals were found (Uribe, 2006). Thus, lowland people also had access to llama caravans, and were thus able to travel through the Atacama.

Pimentel's (2012) study of archaeological routes and inter-nodal spaces suggest two mobility patterns for northern Chile, including a coastal one (in which individuals travelled by foot in order to obtain raw material from the interior) and a llama caravan mode occurring across the interior. The results in this study suggest that both types of mobility patterns were present during the LIP. The archaeological evidence on routes, geoglyphs and the use of llamas for carrying objects in the interior is clear. However, based on the evidence obtained here, it is suggested that economic interactions were not the only reason that encouraged people to move. The outlier individuals observed for both the Atacama and the Tarapacá groups (inland and coast) are quite diverse. For instance, individuals possibly coming from the *altiplano* were at least four in Pica 8

and at least 3 for Quitor 6, definitely not forming colonies in the lowlands. In addition, non-local individuals coming from different areas in the lowlands and pre-cordillera were also reported in this study. Hence, mobility was not reduced exclusively to the altiplano or highland pastoralists. The non-local individuals, including female and males, moved from their origin places at different periods in their lives, following the bone, tooth and hair evidence. But no consistent patterns were observed. Thus, it is suggested here that mobility occurred at a rather individual level, due to cultural, economic, political, or kinship related reasons. Ethnohistorical research in northern Chile (during the XVII to XIX centuries) has shown marriages happened between people from northern Chile, northwestern Argentina and southern Bolivia, frequently, in disregard of their ethnic or cultural affiliations (Martínez, 1998). This historical example could shed some light on the archaeological questions about mobility during the LIP. However, as they are historical documents (and as it will be discussed below) they cannot be directly extrapolated to the past. Thus this information needs to be evaluated carefully together with the archaeological and isotopic evidence.

The archaeology of the LIP in northern Chile has been reconstructed under the influence of ethnohistorical research for decades. Considering the relative temporal proximity of the historical documents with the LIP, social and cultural contexts have been directly extrapolated to the populations inhabiting the Atacama 1000 years ago. This has led to attempts to fit the archaeological evidence with the ethnohistorical documentation. By trying to force the evidence to the ethnohistorical Andean models, an interesting and complex local reality has been left behind, such as the one that characterised the Tarapacá, Atacama-Alto Loa and Antofagasta groups. However, the research started by the mid 1990s to date in northern Chile (Agüero et al., 1997; Agüero et al., 1999; Uribe et al., 2004; Adán et al., 2004, Uribe 2006; Uribe et al., 2007; Agüero et al., 2009; Pimentel, 2012) has provided new perspectives on the local

cultural groups. These local populations show strong individual traditions characterised by a their own cultural expression in the material culture.

The Atacama and Tarapacá Culture show features that are unique to them, suggesting a strong sense identity link within both groups. The presence of specific pottery and textile types, as well as geoglyphs for each area relates to complex ethnic processes. In addition, the many different burial offerings at the local cemeteries suggest a high cultural diversity and interaction occurring between them and other groups.

The application of stable isotope analysis shows that this cultural identity shared by the groups is not only reflected at the material level but also in their diets. This evidence also tells us about everyday practices of the populations forming part of what was described by Bourdieu (1990) as the "*habitus*". In this way, diet becomes an intrinsic part of societies and a useful tool for studying identity (Twiss, 2007).

The isotopic evidence suggests that the Atacama Cultural groups based their diet on terrestrial sources of protein, including mixed C_3 and C_4 fruits and crops, with little in the way of marine resources. All the sites analysed here show a similar pattern, including the groups in the Atacama Oases and the Alto Loa. Even though the presence of structures such as *chullpas* suggests the influence of *altiplano* communities, they maintained distinct local food traditions. This interpretation is consistent with the archaeological funerary contexts and inhabitation sites (Costa-Junqueira, 1988; Schiappacasse et al., 1989; Núñez, 1995; Uribe et al., 2004), that show mainly terrestrial animal remains, together with maize, *algarrobo*, *chañar*, squash and beans. No coastal fauna has been found here, with the exception of shells used for beads (Núñez, 1984; Uribe et al., 2004). This local tradition apparently has deep antecedents since Pestle et al. (2015) and Uribe et al. (2016) found similar distribution of isotope values for earlier sites dating to the Middle Period in the Atacama Oases (Pestle et al., 2015; Uribe et al., 2015).

The Tarapacá Cultural group, on the other hand, shows strong connections between the interior and coast. The isotopic evidence shows that two main dietary groups can be identified in the valleys of Tarapacá. One shows a mixed terrestrial and marine diet (with moderately high $\delta^{13}C_{coll}$ and $\delta^{15}N$, around -10‰ and 15‰), based on C_4 and C_3 resources. The other group shows much higher $\delta^{15}N$ (around 20‰) that could be suggestive of an ingestion of marine resources together with C_4 and C_3 plants. However, this high $\delta^{15}N$ values could also be related to the ingestion of crops fertilised with seabird guano a suggested in Chapters 4, 5 and 6.

Both the Tarapacá and Antofagasta coastal groups show a strong maritime tradition in their isotopic composition with high $\delta^{13}C$ and $\delta^{15}N$ values. This is in agreement with the burial offerings relating to specialised fishing activities. Thus, the coastal groups show a rather more conservative dietary pattern that apparently did not change significantly since early periods of northern Chile's prehistory.

Instead of seeking *altiplano* influence, it is of great relevance to re-consider the idea that local populations acted as different cultural entities with their own internal social dynamics. Unfortunately, this situation happens not only for the LIP but also for the Formative and Middle Periods in which the research has tended to be biased by the assumption of *altiplano* influence on the local populations (Núñez, 1984; Muñoz, 1989; Nado et al., 2012; Pestle et al., 2015; Uribe et al., 2016).

It is suggested that future work will continue the research started by the mid 1990s looking to the local cultural groups and how were the interactions happening between them.

8.2. The non-local individuals: Who were they? Where did they come from? What can they tell us about mobility in the Atacama Desert?

Outlier individuals were identified in the Atacama and Tarapacá Cultural groups on the basis of $\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ results (Table 8.1). It is striking that these individuals not only presented non-local oxygen and strontium isotopic compositions but also consumed different diets compared to the local populations.

For the Atacama groups at least four individuals in the Quitor 6 cemetery presented non-local $^{87}Sr/^{86}Sr$ values (Figure 8.1). Their relatively more radiogenic ratios may suggest a possible origin in the Bolivian Altiplano, the Oriental valleys of the Andes or northwestern Argentina. Similarly high $^{87}Sr/^{86}Sr$ ratios (above 0.71000) have been reported for individuals inhabiting the Tititcaca Basin (Knudson and Price, 2007). In addition, the volcanic strontium isotope composition for the Uyuni-Lake Poopo region also shows increased $^{87}Sr/^{86}Sr$ ratios. However, as yet we lack a robust bio-available strontium isotope baseline for the entire study area and its neighbouring regions, so firm conclusions about their origins cannot be made.

One of these individuals in particular, T54-female individual, shows lower $\delta^{18}O$ values for tooth enamel, (-8.1‰) compared to the rest of the Quitor 6 group, and for the range expected for the Atacama Oases (between -6‰ to -0‰).

Individual T54 (Figure 8.1) also shows ^{13}C-enriched for her tooth enamel (second upper molar), suggesting a heavy reliance in maize during her childhood at around 6 years old. However, bone apatite $\delta^{18}O$ and $\delta^{13}C$ composition is similar to other Quitor 6 local individuals, showing *inter alia* less maize later in life compared to her infancy. Her $\delta^{13}C$ and $\delta^{15}N$ bone collagen values also closely resemble the other Quitor 6 individuals. This evidence suggests she lived in a different geographical region during

her childhood, and lately moved to the Atacama Oases as an adult, eating the local diet during her last years of life.

For the Tarapacá Cultural group, most of the identifiable non-local individuals were observed in the Pica 8 cemetery (Figure 8.2). They show diverse differences in their carbon, nitrogen and oxygen isotope compositions. In contrast to Quitor 6, the radiogenic strontium isotopes suggest only the presence of one identifiable outlier individual. Thus, one may deduce that they originated from geographical regions that happened to have a similar strontium composition and geology to the Pica oases. For example Individuals B0420 and B0453, both females, show very depleted in ^{13}C isotope compositions and $\delta^{18}O$ values for their tooth enamel suggesting a possible origin in the *altiplano*. Their carbon isotopes suggest a consumption of mainly C_3 resources such as potato and *quinoa.* However, both started ingesting the local diets during their late lives. Individual B0453 probably arrived to the Pica oases during her last 10 or more years of life, changing her diet dramatically by consuming fish and maize. Her hair isotope composition (Table 8.1) shows that she kept consuming these resources during her last months of life.

Individual B0420 shows similar low $\delta^{13}C$ and $\delta^{18}O$ values for her bone apatite, suggesting she was still living in the *altiplano* during her last years of life (Figure 8.2). However, her hair keratin results suggest a considerable ingestion of marine food and C_4 resources during her last months of life (Table 8.1). So probably, this female individual arrived to Pica shortly before her death.

Individual B0427 (male), however, does show a different strontium isotopic composition that can be considered as an outlier to the Pica population (Figure 8.2). As individuals B0420 and B0427, his carbon and oxygen isotopes for tooth enamel are quite depleted suggesting an *altiplano* origin for him. However, this would be a different geological

location to the ones suggested for the Quitor-6 outlier individuals. He shows a different $^{87}Sr/^{86}Sr$ ratio (0.70587) compared to the Quitor non-local individuals. It is remarkable that this individual kept an "*altiplano*-menu" during its entire life based on the carbon and nitrogen isotope composition from bone and hair keratin.

Finally, individual B0424 shows in contrast the highest $\delta^{18}O$ values for tooth enamel and bone apatite, but with lower values for his carbon apatite composition. This individual show the highest isotope nitrogen values for the entire Pica 8 sample, including his bone collagen and hair keratin results. In this sense, a possible coastal origin could be proposed for this individual. However, compared to the other oxygen isotope values observed for the Tarapacá Coast, it is suggest this individual could have come from somewhere else along the Pacific coast.

Regarding the coast of Tarapacá four individuals presented different dietary patterns and place of origin (8.2). As discussed in Chapter 5, individuals BM-153 and BM Ed. Ar. 189 present dietary patterns that could be rather related with inland Tarapacá. Individual BM-153, however, started consuming a marine diet during its last months of life as suggested by its hair keratin isotope composition. In contrast, individual BM Ed. Ar. 189 kept its inland diet until death. The oxygen isotope composition of both individuals for tooth enamel resembles the one observed at Pica 8.

The only outlier for strontium isotopes (Figure 8.2) identified here is individual LV-1 C77 (0.71132), showing a ratio strikingly similar to individual T11 from Quitor-6 (0.71136). Their carbon and oxygen isotope results for tooth enamel are also slightly similar (LV-1 C77 $\delta^{13}C$ -8.9‰, $\delta^{18}O$ -8.6‰; T11 $\delta^{13}C$ -9.8‰, $\delta^{18}O$ -7.3‰). Unfortunately, only carbon apatite values are available for individual LV-1 C77 being impossible to know if there was consumption of marine resources or not (since a mixed C_3 and C_4 diet would lead to similar results as for a coastal diet). No information about the funerary contexts for these coastal individuals was available

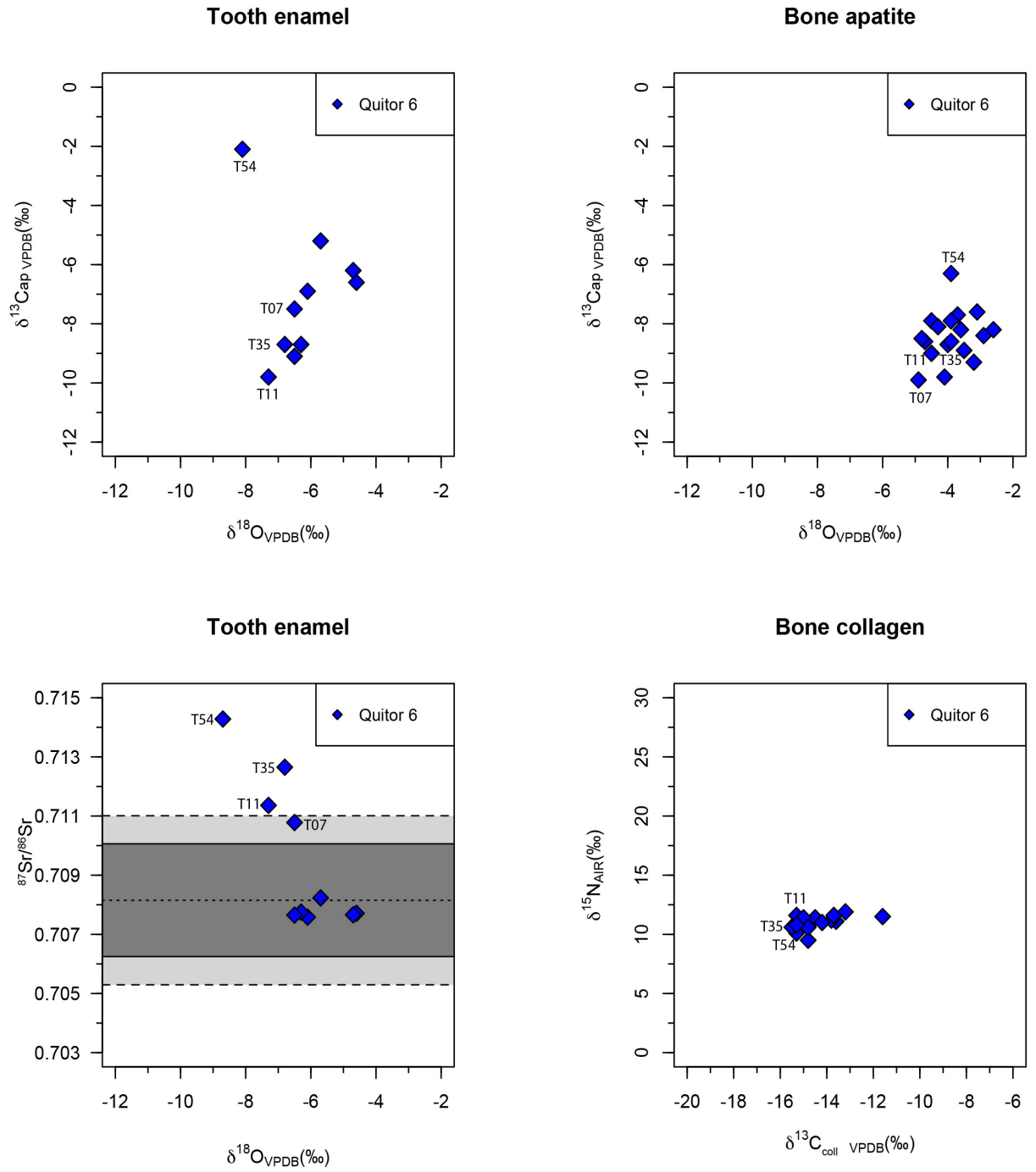


Figure 8.1. Bivariate plot for $\delta^{13}C_{coll}$, $\delta^{13}C_{ap}$, $\delta^{15}N$, $\delta^{18}O$ values in different tissues including tooth enamel, bone apatite collagen of the Quitor 6 site (Atacama cultural group). Outlier individuals are indicated by their reference number.

The offerings found in the burials of all the outlier individuals for Quitor 6 and Pica 8 are diverse. Some of them have local pottery and textiles, while others are associated with non-local pottery or foreign objects such as a shell for T35 in Quitor 6 and a tropical bird for individual B0476 in Pica 8. Some of them are associated with llama caravan activities such as the hooks for attaching sacks on camelids, and the special sacks for transporting objects (Costa-Junqueira, 1988; Zlatar, 1984; Catalán, 2006). The contexts are so different between them that no patterns can be inferred for either the outliers or local individuals.

These data, in combination, suggest that individuals from the Atacama and Tarapacá Cultural groups identified as outliers based on their isotope values, came from different places, retained their diet, costumes or in some cases changed them, and also were buried with a quite diverse set of burial offerings that included local objects in some cases and a mixed set of non-local and local materials in others (Table 8.1).

This evidence strongly suggests the mobility patterns for the LIP in northern Chile were very variable, including male and female individuals travelling at different moments of their lives. Individuals probably came from the *altiplano*, highlands, valleys and coast.

The reconstruction of local baselines for oxygen and strontium isotopes is essential in order to better understand the possible geographical and geological origins of these individuals.

How were they moving? Probably as Pimentel (2012) suggests by foot when coastal individuals travelled to the inlands, or using llama caravans when inland individuals had to cross the desert valleys, highlands and *altiplano*. It is also possible that other types of mobility could have used during the LIP. Future studies combining research on the local routes, inter-nodal sites, geoglyphs and stable isotopes on camelids and ancient human remains could give new insights on the mobility patterns.

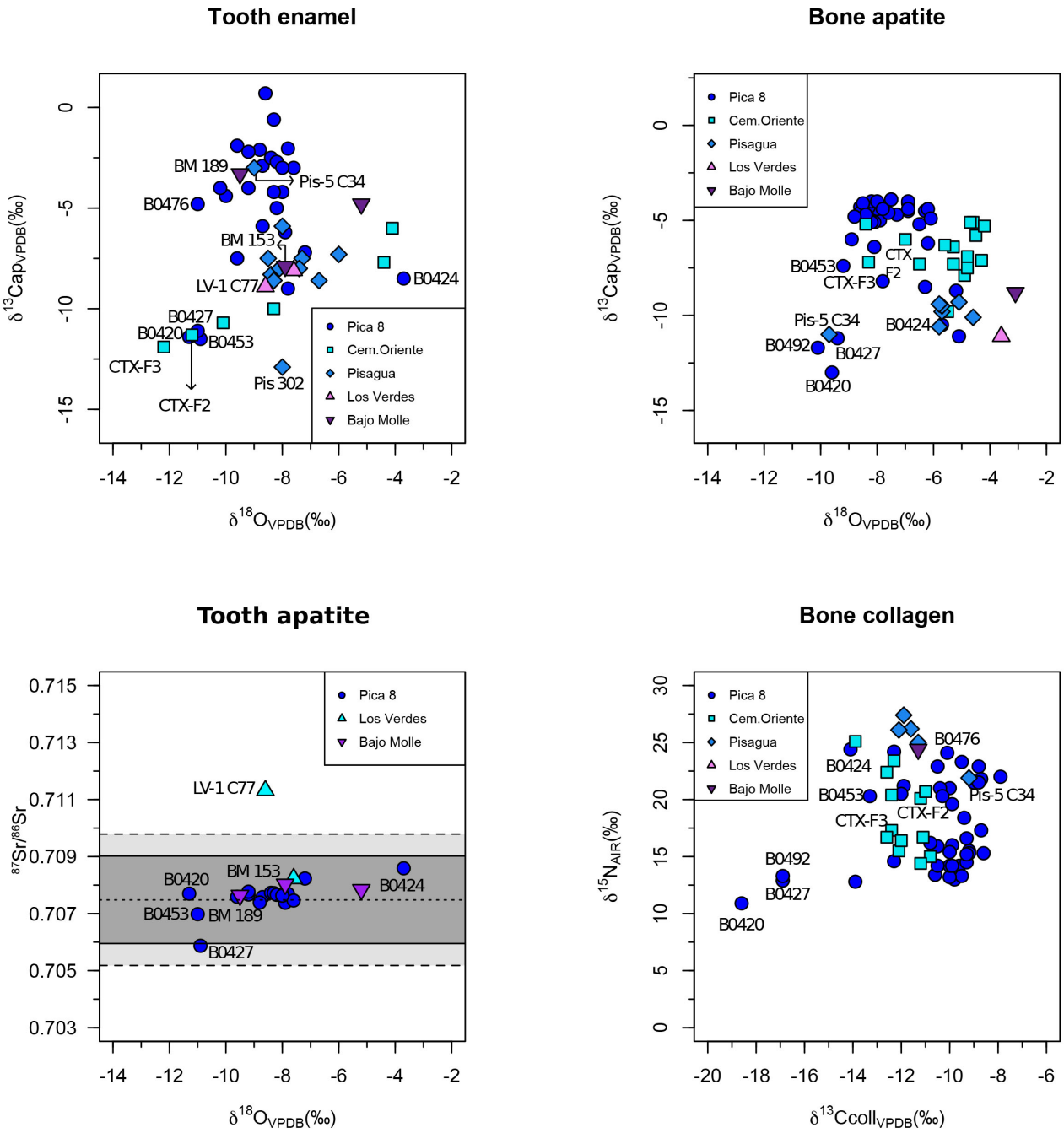


Figure 8.2. Bivariate plot for $\delta^{13}C_{coll}$, $\delta^{13}C_{ap}$, $\delta^{15}N$, $\delta^{18}O$ values in different tissues including tooth enamel, bone apatite collagen of the Pica 8, Cementerio Oriente de Quillagua (Tarapacá Inland) and the Pisagua, Los Verdes and Bajo Molle sietes (Tarapacá Coast). Outlier individuals are indicated by their reference number.

8.3. High $\delta^{15}N$ values in the Atacama Desert: Implications for paleodietary studies

Isotopic Analysis of modern and archaeological flora and fauna of northern Chile has revealed new information about the particularly high $\delta^{15}N$ values observed in the area. It is likely that the high nitrogen isotope compositions observed in plants, animals and humans could be related to the extreme aridity of the area and the complex ecological system of the Pacific Ocean. In addition, the use of seabird guano as fertiliser on crops increasing the $\delta^{15}N$ values dramatically to values close to 40‰ is also a factor. The crops analysed here strongly suggest seabird guano was applied on them, showing considerably high nitrogen isotopes. This is supported by modern experiments (Szpak et al., 2012) on maize using seabird guano have shown how it can deeply affect their $\delta^{15}N$. Question rises now on how to identify the ingestion of crops on the human nitrogen isotopes values, if there was also marine food consumption.

In order to investigate the problem from another angle, radiocarbon dating was carried out on individuals from the Pica 8 cemetery. Paired dates of bone collagen and textile were used for evaluating the impact of the marine reservoir effect on the human bone collagen, assuming there was marine ingestion in Pica. The results were surprising. Individuals with high $\delta^{15}N$ (around 20‰) showed unexpectedly small offsets in the paired radiocarbon dates of human bone collagen and textiles. Hence, the radiocarbon evidence would suggest that even though the $\delta^{15}N$ values were high, no marine reservoir effect was affecting the bone collagen. The high $\delta^{15}N$ values could be then possibly associated with other factors such as the consumption of fertilised crops.

In addition, the complex ecology and trophic webs present in northern Chile's coast also shows high enrichment in ^{15}N for mussels, fish and seals. However, here seals are not at the top of the food chain, having fish higher averages compared to the sea mammals. This pattern was presented in Chapter 4 for archaeological samples, but it

has also been reported for modern marine fauna of northern Chile (Tieszen and Chapman, 1992).

All these factors will play an essential role when interpreting isotopic data from ancient human populations of the Atacama Desert. For this reason, local baselines are essential when reconstructing palaeodiet, following the very particular factors of each environment.

8.4. Conclusions

The results obtained in this research have shown that:

- The Mobility patterns during the LIP were complex and different to what has been proposed during the last 40 years (Murra, 1972, Núñez and Dillehay, 1995). The models related to the vertical archipelago and the gyratory mobility are not supported by the isotopic evidence, suggesting new theories need to be considered when studying human mobility in northern Chile.
- The isotopic evidence for the Atacama Desert during the LIP suggest cultural groups with strong local traditions dominated the area, having important interactions between them and other groups from elsewhere. The results obtained here do not support the presence of *altiplano* colonies in the lowlands. At the same time, different individuals including female and males of different ages would have a travelled the Desert in all directions, discarding an exclusive role of specialised pastoralist groups in charge of trade. Future work is needed in order to understand how the individuals moved and where did they come from.
- Regarding the $\delta^{15}N$ values reported for the area, these could be related to: a direct effect of the aridity of the region on wild plants; the use of seabird guano fertilisers on crops; and effect of the complex trophic chain system present in the Pacific Ocean. All these factors need to be taken into account when working with stable isotope analysis for palaeodietary studies.

Cultural Group	Site	Ind.	Sex	$\delta^{13}C$ Tooth en.	$\delta^{18}O$ Tooth en.	$^{87}Sr/^{86}Sr$ Tooth en.	$\delta^{13}C$ Bone ap.	$\delta^{18}O$ Bone ap.	$\delta^{13}C$ Bone coll	$\delta^{15}N$ Bone coll	$\delta^{13}C$ Hair Ker 6thmonth	$\delta^{13}C$ Hair Ker 6thmonth	$\delta^{13}C$ Hair Ker 1thmonth	$\delta^{13}C$ Hair Ker 1thmonth	Burial offerings
Atacama	Quitor 6	T07	M	-7.5	-6.5	0.71078	-9.9*	-4.9*	-	-	-	-	-	-	Squash object; 114 circular beads of liparite; 4stick fragments that could be have been arrows;
Atacama	Quitor 6	T11	M	-9.8	-7.3	0.71136	-9.0*	-4.5*	-15.3*	11.6*	-	-	-	-	Pottery fragment; 2 squash objects; textile hat; wood fragments
Atacama	Quitor 6	T 35	M	-8.7	-6.8	0.71265	-8.7*	-4.0*	-15.3*	10.1*	-	-	-	-	Marine shell (*Patella vulgata*); 8 pottery fragments; necklace made of liparite.
Atacama	Quitor 6	T 54	F	-2.1	-8.1	0.71428	-6.3	-3.9	-15.3*	10.8*	-	-	-	-	Hooks for attaching bags on camelids; cupper mineral; squash object; local pottery; little wooden box.
Tarapacá Coast	Bajo Molle 1	153	F	-7.9	-7.9	0.70803	-		-	-	-11.0	15.1	-10.7	20.8	No information.
Tarapacá Coast	Bajo Molle Ed. Ar.	189	M	-3.3	-9.5	0.70764	-		-	-	-9.6	13.7	-9.5	14.0	Red-green textile tied to its hair. Pica-Tarapacá style (?).
Tarapacá Coast	Pisagua 5	35	U	-3.0	-9.0	-	-11.0	-9.7	-9.2	21.9	-	-	-	-	No information
Tarapacá Inland	Pica 8	B0420 S-E	F	-11.4	-11.3	0.70770	-13.0*	-9.6*	-18.6*	10.9*	-12.1	18.4	-11.2	22.3	Slingshot; Bag for transport *(talega)* with non-local style; attached set of cactus spines; Pica Gris Alisado pottery.
Tarapacá Inland	Pica 8	B0424 S-I	M	-8.5	-3.7	0.70859	-10.5*	-5.7*	-14.1*	24.4*	-14.1	25.6	-12.9	24.7	No information.

Tarapacá Inland	Pica 8	B0427 S-D	M	-11.5	-10.9	0.70587	-11.2*	-9.4*	-16.9*	12.9*	-16.7	13.1	-15.7	12.6	*Boleadoras* (weapon consisting of three ball-shaped stones attached to a rope with leather strings, used for animal hunting); cupper bracelet; *Carcaj* (quiver) with arrows and hafts.
Tarapacá Inland	Pica 8	B0428 S-I	F	-2.1	-8.8	0.70739	-4.3*	-8.3*	-9.5*	23.3*	-12.6	15	-11.5	15.0	Textile bag for transport (*talega*) broken and with evidence of intense use; pottery; little box for making sounds (little stones found inside); flute; “cowbell”
Tarapacá Inland	Pica 8	B0432 N/R	F	-4.0	-9.2	0.70767	-6.4*	-8.1*	-12.3*	14.6*	-9.3	25.3	-9.4	25.1	No information.
Tarapacá Inland	Pica 8	B0447 S-I	M	-1.9	-9.6	0.70759	-4.0*	-8.2*	-10.4*	21.0*	-9.7	22.6	-9.9	24.0	16 arrows; 2 *carcaj* (quiver); a slingshot; textiles including ceremonial bags (*chuspa*) and normal bags; loincloth; Hooks for attaching bags on camelids; Pica Chiza(1) and Pica Charcollo(1) pottery, *Altiplano* style pottery (3); Atacama-Aiquina(1) and Dupont(1) pottery style; wooden spoon; cactus spine; 1 rodent; leather sandals; among many other objects
Tarapacá Inland	Pica 8	B0453 S-I	F	-11.1	-11.0	0.70698	-7.4*	-9.2*	-12.0*	20.5*	-8.3	22.4	-10.0	19.6	No information.

Tarapacá Inland	Pica 8	B0476 S-E	M	-4.8	-11.0	-	-4.4	-7.8	-10.1	24.1	-8.1	26.2	-8.1	25.6	Textile ceremonial bags (*chuspas*); textile shirt; textile bag for transport (*talega*); baskets; Pica Chiza pottery; panpipes; leather sandals; tropical bird (*Ara ararauna*); Squash objects.
Tarapacá Inland	Cem. Oriente Quill.	CTX. Fun. 2	M	-11.3	-11.2	-	-6.0*	-7.0*	-11.4*	18.7*	-	-	-	-	Atacama and Tarapacá style textiles including shirts and ceremonial bags (*chuspas*).
Tarapacá Inland	Cem. Oriente Quill.	CTX. Fun. 3	F	-11.9	-12.2	-	-7.2*	-8.3*	-12.1*	16.9*	-	-	-	-	Atacama and Tarapacá style textiles including shirts and ceremonial bags (*chuspas*). Pica Charcollo-style pottery.

Table 8.1. Detailed isotopic and burial-offering information for outlier individuals by cultural group. Values obtained in previous research (Santana et al., 2015a,b) are marked with an asterisk (*). Burial offering information was obtained from Costa-Junqueira (1988) for Quitor 6, Zlatar (1984) for Pica 8 and Agüero et al. (1999) for Quillagua. Sector information was included for the Pica 8 individuals below their inventory numbers.

Bibliography

- Adán L, Urbina S. 2010. Arquitectura quebradeña del Complejo Pica-Tarapacá: modos de hacer, opciones de diseño, rasgos significativos y decisiones funcionales. In *Actas del XVII Congreso Nacional de Arqueología Chilena*. Ediciones Kultrún: Valdivia, 865-876
- Agüero C. 1995. El cementerio "Protonazca" de Pisagua (D), Colección Max Uhle (II) Estudio de la Textilería. *Actas del XII Congreso Nacional de Arqueología Chile*na: Antofagasta, 7-15
- Agüero C, Uribe M, Ayapa P, Cases B. 1997. Variabilidad textil en el valle de Quillagua durante el Período Intermedio Tardío: Una aproximación a la etnicidad. *Estudios Atacameños* 17: 263-290
- Agüero C, Uribe M. Ayala P, Cases B. 1999. Una aproximación arqueológica a la etnicidad, y el rol de los textiles en la construcción de la identidad cultural en los cementerios de Quillagua (Norte de Chile). *Gaceta Arqueológica Andina* 25: 167-197
- Aguero C. 2006. Vestuario e identidad cultural en Tarapacá durante el Período Intermedio Tardío. In: Actas del XVII Congreso Nacional de Arqueología Chilena I. Valdivia: Ediciones Kultrún. p 33-45
- Ambrose, S. 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archeological Science* 17:431-451
- Ambrose SH. 1991. Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. *Journal of Archeological Science* 18:293–317
- Ambrose S, DeNiro M. 1986. The isotopic ecology of East African mammals. Oecologia 69:395–406.
- Ambrose SH, Norr L. 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In *Prehistoric Human Bone: Archaeology at the Molecular Level. Springer-Verlag*, Lambert JB, Grupe G. (eds.). Springer-Verlag: New York; 1-37
- Andrade P, Fernandes R, Codjambassis K, Urrea J, Olguín L, Rebolledo S, Lira F, Aravena C, Berríos M. 2015. Subsistence continuity linked to consumption of marine protein in the formative period in the interfluvic coast of northern Chile: re-assesing contacts with agropastoral groups from highlands. *Radiocarbon* 57: 679-688

- Aravena R. 1995. Isotope hydrology and geochemistry of northern Chile groundwaters. *Bulletin de l'Instut Français d'Etudes Andines* 24: 495-503.
- Aravena R, Suzuki O, Peña H, Pollastri A, Fuenzalida H, Grilli A. 1999. Isotopic compostion and origin of the precipitation in Northern Chile. *Applied Geochemistry* 14: 411-422
- Aubert D, Probst A, Stille P, Viville D. 2002. Evidence of hydrological control of Sr behaviour in stream water (Strengbach catchment, Vorges Mountains, France). *Applied Geochemistry* 17: 285-300
- Aufderheide A. Kelley M, Rivera R, Gray L, Tieszen L, Iversen L, Krouse R, Carevic A. 1994. Contributions of chemical dietary reconstruction to the assessment of adaption by ancient highland inmigrants (Alto Ramírez) to coastal conditions at Pisagua, North Chile. *Journal of Archaeological Science* 21: 515-524
- Aufderheide AC, Santoro CM. 1999. Chemical paleodietary reconstruction: Human populations at late prehistoric sites in the Lluta Valley of northern Chile. *Revista Chilena de Historia Natural* 72: 237-250
- Ballester B, Clarot A. 2014. *La gente de los túmulos de tierra, estudio, conservación y difusión de colecciones arqueológicas de la comuna de Mejillones*. Gráfica Marmor: Santiago
- Ballester B, Clarot A, Llagostera A. 2014. El Cementerio de Auto Club de Antofagasta y la sociedad litoral entre los 1000 y 1450 DC. *Hombre y Desierto* 18: 186-211
- Beard BL, Johnson CM. 2000. Strontium isotope composition of skeletal material can determine the birthplace and geographic mobility of humans and animals. *Journal of Forensic Sciences* 45: 1049-1061
- Bentley A, Price TD, Stephan E. 2004. Determining the "local" 87Sr/86Sr range for archaeological skeletons: a case study from Neolithic Europe. J Archaeol Sci: 365-375
- Bentley RA. 2006. Strontium isotopes from the earth to the archaeological skeleton: a review. *Journal of Archaeological Method and Theory* 13: 135-187
- Berenguer J, Dauelsberg P. 1989. El Norte Grande en la órbita de Tiwanaku. In *Culturas de Chile Prehistoria*, Hidalgo J, Schiappacasse V, Niemeyer H, Aldunate C, Solimano I (eds). Andrés Bello: Santiago; 129-180
- Berenguer J. *Caravanas interacción y cambio en el Desierto de Atacama*. PhD Dissertation, University of Illinois: Illinois

- Böhlke JK, Ericksen GE, Revesz K. 1997. Stable isotope evidence for an atmospheric origin of desert nitrate deposits in northern Chile and southern California, USA. *Chemical Geology* 136: 135-152
- Bogaard A, Heaton T, Poulton P, Merbach I. 2007. The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. *Journal of Archaeological Science* 34: 335–343
- Boschetti T, *et al*. 2007. New and past geochemical data on fresh to brine waters of the Salar de Atacama and Andean Altiplano, northern Chile. *Geofluids* 7: 33-50
- Briones L, Núñez L, Standen V. 2005. Geoglifos y tráfico prehipánico de caravanas de llamas en el desierto de Atacama (Norte de Chile). *Chungara* 37: 195-223.
- Brock F, Higham T, Ditchfield P, Bronk Ramsey C. 2010. Current pretreatment methos for AMS radiocarbon dating at the Oxford Radiocarbon Accelarator Unit (ORAU). Radiocarbon 52: 103-112
- Bronck Ramsey C y Lee S. 2013. Recent and planned developments of the program OxCal. Radiocarbon 55: 720-730
- Browman DL. 1980. Tiwanaku expansión and Altiplano economic patterns. *Estudios Arquelógicos* 5: 107-120
- Buikstra J, Ubelaker D. 1994. *Standards for data collection from human skeletal remains*. Archaeological Survey Research Series 44. Fayetteville: Arkansas
- Cadwallader L, Beresford-Jones D, Whaley OQ, O'Conell TCO. 2012. The signs of maize? A reconsideration of what $\delta^{13}C$ Values say about Palaeodiet in the Andean Region. *Human Ecology* 40: 487-509
- Camus P. 2001. Biogeografía marina de Chile continental. *Revista Chilena de Historia Natural* 74: 587-617
- Capo RC, Stewart BW, Chadwick OA. 1998. Strontium isotopes as tracers of ecosystems processes: Theory and Methods. *Geoderma* 82: 197-225
- Carré M, Jackson D, Maldonado A, Chase B, Sachs J. Variability of 14C reservoir age and air-sea flux of CO2 in the Peru-Chile upwelling region during the past 12.000 years. Quaternary Research. DOI: 10.1016/j.yqres.2015.12.002
- Cases B, Rees C, Pimentel G, Labarca R, Leiva D. Sugerencias desde un contexto funerario en un "espacio vacío" del Desierto de Atacama. *Boletín del Museo Chileno de Arte Precolombino* 13: 51-70
- Castro V, Aldunate C, Berenguer José. 1984. Orígenes altiplánicos de la Fase Toconce. *Estudios Atacameños* 7: 159-178

- Catalán D. 2006. Una aproximación a las expresiones simbólicas e ideológicas tarapaqueñas a partir del ritual funarario de Pica 8 y la costa de Iquique (Período Intermedio Tardío). Undergrad dissertation. Universidad de Chile: Santiago
- Cervellino M, Téllez F. 1980. Emergencia y desarrollo de una aldea prehispánica de Quillagua, Antofagasta. *Contribución Arqueológica* 1: 1-235
- Clarke J. 2006. Antiquity of aridity in the Chilean Atacama Desert. *Geomorphology* 73: 101-114
- Clarot A, Méndez A, Ballester B. 2014. *Único y Fuerte. El chango prehispánico del Museo de Mejillones*. Museo Muncipal Mejillones: Mejillones
- Clarot A, Méndez A, Ballester B. 2014-2015. Un costeño del Desierto de Atacama: acercamiento al mode de vida en el Período Intermedio Tardío mediante imagenología e isótopos estables. *Taltalia* 7-8: 39-60
- Chisholm BS, Nelson DE, Schwarcz HP. 1982. Stable carbon isotope ratios as a measure of marine versus terrestrial protein in ancient diets. Science 216: 1131-1132.
- Cock G. 1981. El ayllu en la sociedad andina: alcances y perspectivas. *Etnohistoria y Antropología Andina* 17: 231-253
- Costa-Junqueira MA. 1988. Reconstitución física y cultural de la población tardía del cementerio de Quitor-6 (San Pedro de Atacama). *Estudios Atacameños* 9:99-126
- Costa-Junqueira MA, Sanhueza J. 1976. *Poblaciones precolombinas de la costa norte de Chile: restos oseas humanos de los cementerios Punta Blanca y Auto Club (Antofagasta)*. Seminario Medio Integral. Universidad del Norte: Antofagsta
- Craig A. 1982. Ambiente Costero del Norte de Chile. Chungará 9: 4-20
- Craine J, Elmore A , Aidar M, Bustamante M, Dawson T, Hobbie E, Kahmen A, Mack M, McLauchlan K, Michelsen A, Nardoto G, Pardo L, Peñuelas J, Reich P, Schuur E, Stock W, Templer P, Virginia R, Welker J, Wright I. 2009. Global patterns of foliar nitrogen isotopes and their relationships with climate, mycorrhizal fungi, foliar nutrient concentrations and nitrogen availability. New Phytol 183: 980-992
- Dansgaard W. 1964. *Stable isotopes in precipitation*. Tellus 16: 436–68
- Davidson J, de Silva S. 1995. Late Cenozoic magmatism of the Bolivian Altiplano. Contrib Mineral Petrol 119: 387-408

- Daux V, Lécuyer C, Herán MA, Amiot R, Simon L, Fourel F, Martineau F, Lynnerup N, Reychler H, Escarguel G. 2008. Oxygen isotope fractionation between human phosphate and water revisited. *Journal of Human Evolution* 55: 1138-1147
- DeNiro M. 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* 317: 806–809
- Díaz F. 2014. *A late quaternary record of climate, vegetation and nitrogen cycle at the limit of life using fossil rodent middens from the Atacama Desert*. Doctoral Thesis. Pontifica Universidad Católica de Chile: Santiago
- Díaz F, Frugone M, Gutiérrez R, Latorre C. 2016. Nitrogen cycling in an extreme hyperarid environment inferred from $\delta^{15}N$ analyses of plants, soils, and herbivore diet. *Nature Scientific Reports*. DOI: 10.1038/srep22226
- Díaz-Zorita Bonilla M, Drucker DG, Richardin P, Silva-Pinto V, Sepúlveda M, Bocherens H. 2015. Marine food consumption in coastal northern Chilean (Atacama Desert) populations during the Formative Period: Implications of isotopic evidence (C,N,S) for the Neolithic process in south Central Andes. *Journal of Archaeological Science: Reports*. DOI.10.1016/j.jasrep.2016.01.026
- Ehleringer JR, Rundel PW, Palma B, Mooney HA. 1998. Carbon isotope ratios of Atacama Desert plants reflect hyperaridity of region in northern Chile. *Revista Chilena de Historia Natural* 71: 79-86
- Ericksen G. 1983. The Chilean nitrate deposits. *American Scientist* 71: 1-37.
- Evans R, Ehleringer JR. 1994. Plant $\delta^{15}N$ values along a fog gradient in the Atacama Desert, Chile. *Journal of Arid Environments* 28: 189-193
- Evans JA, Montgomery J, Wildman G. 2009. Isotopes domain mapping of $^{87}Sr/^{86}Sr$ biosphere variation on the Isle of Skye, Scotland. *Journal of the Geological Society*, London 166: 617-631
- Falabella F, Planella MT, Aspillaga E, Sanhueza L, Tykot R. 2007. Dieta en sociedades alfareras de Chile Central: Aporte de análisis de isótopos estables. *Chungara* 39: 5-27
- Faure G. 1986. *Principles of Isotope Geology*. John Wiley: New York
- Faure G, Powell T. 1972. *Strontium isotope geology*. Springer: New York
- Fernández J, Panarello HO. 1999-2001. Isótopos del carbono en la dieta de herbívoros y carnívoros de los Andes Jujeños. *Xama* 12-14: 71-85

- Finucane B. 2007. Mummies, maize, and manure: multi-tissue stable isotope analysis of late prehistoric human remains from the Ayacucho Valley, Perú. *Journal of Archaeological Science* 34: 2115-2124
- Fogel ML, Tuross N, Owsley D. 1989. Nitrogen istope tracers of human lactation in modern and archaeological populations. *Carnegie Institute Year Book* 88: 111-117
- Fontugne, M. et al. 2004. Radiocarbon reservoir age variations in the south Peruvian upwelling during the Holocene. *Radiocarbon* 46(2):531–537
- Fraser RA, Bogaard A, Heaton THE, Charles M, Jones G, Christensen BT, Halstead P, Merbach I, Poulton PR, Sparkes D, Styring AK. 2011. Manuring and stable nitrogen isotope ratios in cereals and pulses: towards a new archaeobotanical approach to the inference of land use and dietary practices. Journal of Archeological Science 38: 2790-2804
- Gallardo F. Cornejo L. Sánchez R. Cases B. Román A, Deza A. 1993. Arqueología en el valle de Quillagua, Río Loa, Norte de Chile. *Gaceta Arqueológica Andina* 23: 125-138
- García M, Vidal A. 2006. Distribución y contexto de uso de las plantas arqueológicas del asentamiento Camiña-1 (1250-1450 años DC), Región de Tarapacá. In: Actas del XVII Congreso Nacional de Arqueología Chilena. Ediciones Kultrún: Valdivia, 1225-1235
- Gayo EM, Latorre C, Santoro CM. 2015. Timing occupation and regional settlement patterns revealed by time-series analyses of an archaeological radiocarbon database for the South-Central Andes (16º-25º S). *Quaternary Internationa*l 356: 4-14
- Godoy B, Wörner G, Kojima S, Aguilera F, Simon K. 2014. Low-pressure evolition of arc mamgas in thickened crust: the San Pedro-Linzor volcanic chain, Central Andes, Northern Chile. *Journal of South American Earth Sciences* 52: 24-42
- González, J., 2006. Arqueofauna del complejo Pica-Tarapacá (950-1450 años DC) I región de Tarapacá, Norte de Chile. In *Actas del XVII Congreso Nacional de Arqueología Chilena*, Sociedad Chilena de Arqueología (eds). Ediciones Kultrún: Valdivia; 59-69
- Grove M, Baker P, Cross S, Rigsby A, Seltzer G. 2003. Application of strontium isotopes to understanding the hydrology and paleohydrology of the altiplano, Bolivia-Peru. *Paleogeography Paleoclimatology Paleoecology* 194:281-297.

- Gutiérrez J, López-Cortes F, Marquet P. 1998. Vegetation in an altitudinal gradient along the Río Loa in the Atacama Desert of northern Chile. *Journal of Arid Environments* 40: 383-399
- Hartman, G and Danin, A. 2010. Isotopic values of plants in relation to water availability in the Eastern Mediterranean region. *Oecologia* 162: 837-852
- Hastorf CA, DeNiro MJ. 1985. Alteration of $^{15}N/^{14}N$ and 13C/12C ratios of plant matter during the initial stages of diagenesis: Studies utilizing archaeological speciments from Peru. *Geochimica et Cosmochimica Acta* 68: 61-72
- Heaton T, Vogel J, Chevallerie G, Collet G. 1986. Climatic influence on the isotopic composition of bone nitrogen. Nature 322: 822-823.
- Heaton T. 1987. The $^{15}N/^{14}N$ ratios of plants in South Africa and Namibia: Relationship to climate and coastal/saline environments. *Oecologia* 74: 236-246.
- Hedges REM, Reynard L. 2007. Nitrogen isotopes and the trophic level of humans in archaeology. *Journal of Archeological Science* 34: 1240-1251.
- Hedges, R.E.M. et al. 2007. Collagen turnover in the adult femoral mid-shaft: modeled from anthropogenic radiocarbon tracer measurements. *American Journal of Physical Anthropology* 133: 808-16.
- Hillson, S. 1996. Dental Anthropology. Cambridge University Press: Cambridge
- Hodell DA, Quirn RL, Brenner M, Kamenov G. 2004. Spatial variation of strontium isotopes ($^{87}Sr/^{86}Sr$) in the Maya región: A tool for tracking ancient human migration. *Journal of Archaeological Science* 31: 585-601
- Hogg AG, Blackwell PG, Niu M, Buck CE, Guilderson TP, Heaton TJ, Palmer JG, Reimer PJ, Reimer RW, Turney CSM, Zimmerman SRH. 2013. SHCal13 Southern Hemisphere Calibration, 0-50.000 years cal BP. *Radiocarbon* 55: 1-15.
- Holmgren M, Scheffer M. 2001. El Niño effects on the dynamics of terrestrial ecosystems. *Trends in Ecology and Evolution* 16: 89-94
- Honch N, Higham T, Chapman J, Gaydarska B, Hedges REM. 2006. A palaeodietary investigation of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) in human and faunal bones from the Copper Age cemeteries of Varna I and Durankulak, Bulgaria. *Journal of Archaeological Science* 33: 1493-1504.
- Houston J. 2006. Evaporation in the Atacama Desert: An empirical study of spatio-temporal variation and their causes. *Journal of Hydrology* 330: 402-412

- Jaksic F, Torres-Mura JC, Cornelius C and Marquet P. 1999. Small mammals of the Atacama Desert (Chile). Journal of Arid Environments 42: 129-135
- Julien CJ. Guano and Resource Control in Sixteenth Century Arequipa. In *Andean Ecology and Civilization. An interdisciplinary perspective on Andean Ecological Complementarity*. Masuda S, Shimada I, Morris C (eds.). University of Tokyo Press: Tokyo, 185-231
- Katzenberg MA, Pfeiffer S. 1995. Nitrogen isotope evidence for weaning age in a nineteenth century Canadian skeletal sample. In *Bodies of evidence: reconstructing history through skeletal analysis*. Grauer AL (eds.). Wiley-Liss: New York, 221-235
- Killian Galván V, Oliszewski N, Olivera DE, Panarello HO. 2014. Intraspecific variability in the $\delta^{13}C$ and $\delta^{15}N$ values of archaeological samples of Zea mays cobs (Northeastern Argentinian Puna). In *Physical, Chemical and Biological Markers in Argentine Archaeology: Theory, Methods and Applications*. Kligmann D, Morales M (eds.). BAR International Series Archaeopress: Oxford, 39-51
- Knudson K, Price TD. 2007. Utility of multiple chemical techniques in archaeological residential mobility studies: case studies from Tiwanaku- and Chiribaya- affiliated sites in the Andes. *American Journal of Physical Anthropology* 132: 25-39
- Knudson K. 2009. Oxygen Isotope Analysis in a Land of Environmental Extremes: The Complexities of Isotopic Work in the Andes. *International Journal of Osteoarchaeology* 19: 171-191
- Knudson K, Torres-Rouff C. 2009. Investigating cultural heterogeneity in San Pedro de Atacama, Northern Chile, through biogeochemestry and bioarchaeology. *American Journal of Physical Anthropology* 138: 473-485
- Knudson K, Pestle W, Torres-Rouff C, Pimentel G. 2010. Assessing the life history of an andean traveller through biogeochemistry: Stable and radiogenic isotope analyses of archaeological human remains from northern Chile. *International Journal of Osteoarchaeology* 22: 435-451
- Knudson, K. y C. Torres-Rouff 2014. Cultural diversity and paleomobility in the Andean Middle Horizon: radiogenic strontium isotope analyses in the San Pedro de Atacama oases of northern Chile. *Latin American Antiquity* 25:170-188

- Koch PL, Tuross N, Fogel ML. 1997. The Effects of Sample Treatment and Diagenesis on the Isotopic Integrity of Carbonate in Biogenic Hydroxylapatite. *Journal of Archaeological Science* 24: 417–429
- Latcham, R. 1933. Notas preliminares de un viaje arqueológico a Quillagua. *Revista Chilena de Historia Natural* 27: 130-138
- Latcham, R. 1938. *Arqueología de la región atacameña*. Prensas en la Universidad de Chile: Santiago
- Latorre, C., J. Betancourt, K. Rylander, J. Quade and O.Matthei. 2003. A vegetation history from the arid prepuna of northern Chile (22-23ºS) over the last 13.500 years. *Palaeogeography, Palaeoclimatology, Palaeoecology* 194: 223-246
- Latorre C, Betancourt J, Rech J, Quade J, Holmgren C, Placzek C, Maldonado A, Vuille M and Rylander K. 2005. Late Quaternary history of the Atacama Desert. In *Archaeology and Environmental History of the Southern Deserts*, Smith M and Hesse P (eds). National Museum of Autralia Press, Australia.
- Latorre C, De Pol-Hoz R, Carter C, Santoro C. Using archaeological shell middens as a proxy for past local coastal upwelling in northern Chie. Quaternary International. IN PRESS.
- Lee-Thorp J, Sealy J, van der Merwe N. 1989. Stable Carbon Isotope Ratio Differences Between Bone Collagen and Bone Apatite, and their Relationship to Diet. *Journal of Archaeological Science* 16: 585–599
- Lee-Thorp J, Sponheimer M. 2003. Three case studies used to reassess the reliability of fossil bone and enamel isotope signals for palaeodietary studies. *Journal of Anthropological Archaeology* 22: 208-216
- Longin R. 1971. New method of collagen extraction for radiocarbon dating. Nature 230:241-242
- Longinelli, A. 1984. Oxygen isotopes in mammal bone phosphate: A new tool for paleohydrological and paleoclimatoligical research? *Geochimica et Cosmochimica Acta* 48: 385-390
- López P. 1979. *Emergencia y Desarrollo de una aldea Prehispánica en Quillagua, II región*. Universidad de Chile: Santiago.
- López, P., I. Cartajena y L. Núñez 2013. Análisis de isótopos estables en colágeno de huesos de camélidos de Quebrada de Tulán, Puna de Atacama, Período Formativo Temprano (ca. 3100-2400 AP). *Chungara Revista de Antropología Chilena* 45:237-247.

- Luz B, Kolodny Y, Horowitz M. 1984. Fractionation of oxygen isotopes between mammalian bone-phosphate and environmental drinking water. Geochimica et Cosmochimica Acta 48: 1689-1693.
- Magaritz M, Aravena R, Peña H, Suzuki O, Grilli A. Water chemistry and isotope study of streams and springs in northern Chile. *Journal of Hydrology* 108: 323-341.
- Magaritz M, Aravena R, Peña H, Suzuki O, Grilli A. 1990. Deep circulation of groundwater in the Andes: source of groundwater in the deserts of Northern Chile. *Ground Water* 28: 513-517
- Mamani M, Wörner G, Sempere T. 2010. Geochemical variations in igneous rocks of the Central Andean orocline (13ºS to 18ºS): tracking crustal thickening and magma generation through time and space. *Geological Society of America Bulletin* 122 (1/2): 162-182.
- Marquet, P., Bozinovic F, Bradshaw G, Cornelius C. González H, Gutierrez J, Hajek E, Lagos J, Lopez-Cortes F, Nuñez L, Rosello E, Santoro C, Samaniego H, Standen V, Torres-Mura J and Jaksic M. 1998. Los ecosistemas del desierto de Ataca,a y área andina adyacente en el norte de Chile. Revista Chilena de Historia Natural 71: 593-617
- Martínez JL. 1998. *Pueblos del chañar y el algarrobo. Los Atacamas en el siglo XVI*I. DIBAM: Santiago, Chile.
- Moragas C. 1995. Desarrollo de las Comunidades Prehispánicas del Litoral Iquique-desembocadura Río Loa. *Hombre y Desierto* 9: 65-80.
- Murra J. 1972. El "control vertical" de un máximo de pisos ecológicos en la economía de las sociedades andinas. In *Visita a la provincia de León de Huánuco en 1562, Iñigo Ortiz de Zúñiga*, Murra J (eds). Universidad Emilio Valdizán: Huánuco; 429-472
- Nado K, Marsteller S, King L, Daverman B, Torres-Rouff C, Knudson K. 2012. Examining local social identities through patterns of biological and cultural varition in the Solcor *ayllu*, San Pedro de Atacama, Chile. *Chungara* 44: 341-357.
- Nielsen, A. 2009. Pastoralism and the non-pastoralism world in the late pre-Columbian history of the Southern Andes (1000-1535). *Nomadic Peoples* 13: 17-35
- Núñez L. 1965. Desarrollo Cultural Prehispánico del Norte de Chile. *Estudios Arqueológicos* 1: 37-106
- Núñez L. 1984. *Tráfico de complementariedad de recursos entre las tierras altas y el Pacífico en el área Centro-Sur Andina*. University of Tokyo: Tokyo.

- Núñez L, Santoro C. 1988. Cazadores de la puna seca y salda del área centro-sur andina (norte de Chile). *Estudios Atacameños* 9: 3-59
- Núñez L. 1995. *Cultura y conflicto en los oasis de San Pedro de Atacama*. Editorial Universitaria: Santiago.
- Núñez L, Dillehay T, 1995 [1978]. *Movilidad giratoria, armonía social y desarrollo en los Andes Meridionales: patrones de tráfico e interacción económica*. Universidad del Norte: Antofagasta.
- O'Connell TC, Hedges REM. 1990. Isotopic comparison of hair and bone: archaeological analyses. *Journal of Archaeological Science* 26: 661-665.
- O'Connell TC, Hedges REM, Healy MA, Simpson AHRW. 2001. Isotopic comparison of hair, nail and bone: modern analysis. *Journal of Archaeological Science* 28: 1247-1255.
- O'Leary M. 1981. Carbon Isotope Fractionation in Plants. *Phytochemistry* 20:553–567.
- Ortlieb, L. et al. 2011. Marine radiocarbon reservoir effect along the northern Chile–southern Peru coast (14–24°S) throughout the Holocene. *Quaternary Research* 75: 91–103.
- Ortiz C, Aravena R, Briones E, Suárez F, Tore C and Muñoz JF. 2013. Sources of surface wáter for the Soncor ecosystem, Salar de Atacama basin, northern Chile. *Hydrological Sciences Journal* 59(2): 336-350.
- Pacheco A, Retamal R, Mendez-Quiros. 2016. Violence in northern Chile during the Late Intermediate Period (AD 1000-1450) revisited utilizing three archaeological indicators. In *Beyond the war: archaeological approaches to violence*. Vila A, García A. Cambridge Scholars Publishing: Cambridge, 23-48
- Owen, B.D. 2002. Marine carbon reservoir age estimates for the far south coast of Peru. *Radiocarbon* 44: 701-708
- Passey B, Robinson T, Ayliffe L, Cerling T, Sponheimer M, Dearing M, Roeder B, Ehleringer J. 2005. Carbon isotope fractionation between diet, breath CO 2, and bioapatite in different mammals. *Journal of Archaeological Science* 32:1459–1470.
- Pestle WJ, Torres-Rouff C, Gallardo F, Ballester B, Clarot A. 2015. Mobility and Exchange among Marine Hunter-Gatherer and Agropastoralist Communities in the Formative Period Atacama Desert. *Current Anthropology* 56: 121-133.
- Pimentel G. 2012. *Redes viales prehispánicas en el Desierto de Atacama: viajeros, movilidad e intercambio*. PhD Dissertation, Universidad Católica del Norte-Universidad de Tarapacá: San Pedro de Atacama, Chile.

- Placzek C, Quade J, Patchett J. 2011. Isotopic tracers of Paleohydrologic Change in large lakes of the Bolivian Altiplano. *Quaternary Research* 75(1): 231-244.
- Pin C, Briot D, Bassin C, Poitrasson F (1994) Concominant Separation of strontium and samarium–neodymium for isotopic analysis in silicate samples, based on specific extraction chromatography. *Analytical Chemistry Acta*, 298, 209–217
- Pinto, R. 2001. Presencia de Tillandsia virescens en el sistema de Tillandsiales de la cordillera de la costa de Iquique, norte de Chile. XIII Reunión Anual Sociedad de Botánica de Chile. Gayana Botánica 58: 75-90.
- Poulson S, Kuzminsky S, Scott G, Standen G, Arriaza B, Muñoz I, Dorio L. 2013. Paleodiet in northern Chile through the Holocene: extremely heavy $\delta^{15}N$ values in dental calculus suggest a guano-derived signature? *Journal of Archaeological Science* 40: 4576-4585.
- Price TD, Johnson cm, Ezzo JA, Erickson J, Burton J. 1994. Residential Mobility in the Prehistoric Southwest United Stated: A Preliminary Study using Strontium Isotope Analysis. *Journal of Archaeological Science*, 21: 315-330.
- Price D, Manzanilla L, Middleton W. 2000. Immigration and the ancient city of Teotihuacan in Mexico: a study using strontium isotope ratios in human bone and teeth. *Journal of Archaeological Science* 27: 903-913.
- Price TD, Knipper C, Grupe C, Smrcka V. 2004. Strontium isotopes and prehistoric human migration: the Bell Beaker period in Central Europe. *European Journal of Archaeology* 7: 9-40
- Price TD, Ambrose SH, Bennike P, Heinemeier J, Noe-Nygaard N, Brinch Petersen E, Vang Petersen P, Richards M. 2007. New information on the Stone Age graves at Dragsholm, Denmark. *Acta Archaeologica* 78(2): 193-219.
- Quade J, Rech JA, Latorre C, Betancourt JL, Gleeson R, Kalin MTK. Soils at the hyperarid margin: The isotopic composition of soil carbonate from the Atacama Desert, Northern Chile. *Geochimica et Cosmochima Acta* 71: 3772-3795
- R Core Team. 2013. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing: Vienna, Austria. URL http://www.R-project.org/
- Retamal R, Pacheco A, Uribe M. 2012. Dimorfismo sexual, distribución etaria y longevidad del cementerio Pica 8 (período Intermedio Tardío, 950-1450 DC, Norte Grande de Chile). *Estudios atacameños* 44:89–106

- Richards M, Hedges REM. 1999. Stable isotope evidence of similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic Coast of Europe. Journal of Archaeological Science 26: 717-722.
- Roberts A, Pate D, Petruzzelli B, Carter C, Westaway MC, Santoro CM, Swift J, Maddern T, Jacobsen G, Bertuch F, Rothhammer F. 2013., Retention of hunter–gatherer economies among maritime foragers from Caleta Vitor, northern Chile, during the late Holocene: evidence from stable carbon and nitrogen isotopic analysis of skeletal remains. *Journal of Archaeological Science* 40: 2360-2372
- Robins S, New S. 1997. Markers of bone turnover in relation to bone health. *Proceedings of the Nutrition Society* 56: 903-914
- Rostworowski M. 1986. La región del Colesuyu. *Chungará* 1986: 127-135.
- Rozanski K, Araguas-Araguas L, Gonfiantini R. 1993. Isotopic patterns in modern global precipitation. In: Swart PK, Lohmann KC, McKenzie J, Savin S, editors. Climate Change in Continental Isotope Records. Geophys. Monogr 78: Washington, 1-36
- Rundel P et al. 1991. The Phytogeography and Ecology of the Coastal Atacama and Peruvian Deserts. *Aliso* 13: 1-49
- Samec CT. 2012. Variabiliad dietaria en camélidos de la Puna: un modelo actual a partir de la evidencia isotópica. In *Entre Pasados y Presentes III. Estudios Contemporáneos en Ciencias Antropológicas. Colección Investigación y Tesis.* Kuperszmit et al. (eds). MNEMOSYNE: Buenos Aires, 666-683.
- Samec CT. 2014. Ecología isotópica en la Puna Seca Argentina: un marco de referencia para el estudio de las estrategias de pastoreo en el pasado. *Cuadenos del Instituto Nacional de Antropología y Pensamiento Latinoamericano*, Series Especiales 2: 61-85.
- Samec CT, Morales MR, Yacobaccio HD. 2014. Exploring human subsistence strategies and environmental change through stable isotopes in the dry Puna of Argentina. *International Journal of Osteoarchaeology* 24: 134-148
- Samec CT, Yacobaccio HD, Panarello HO. 2015. Carbon and nitrogen isotope composition of natural pastures in the dry Puna of Argentina: a baseline for the study of prehistoric herd management strategies. *Archaeological and Anthropological Sciences.* DOI: 10.1007/s12520-015-0263-2
- Sanhueza J. 1982. Avances en las investigaciones sobre la prehistoria de la costa- sur interfluvial de Iquique I región-Chile. In *Actas del IX Congreso Nacional de Arqueología*. Museo Arqueológico de La Serena: La Serena, 43-59.

- Sanhueza J. 1985. Poblaciones tardías en playa “Los Verdes” costa sur de Iquique I región de Chile. *Chungará* 14: 45-60
- Santana F, Herrera MJ, Uribe M. 2012. Acercamiento a la paleodieta en la costa y quebradas tarapaqueñas durante el período Formativo: Análisis de isótopos estables a partir de tres casos de estudio. *Boletín de la Sociedad Chilena de Arqueología* 41-42: 109-126.
- Santana, F., Lee-Thorp, J.A., Schulting, R.J. and Uribe, M. 2015a. Isotopic evidence for divergent diets and mobility patterns in the Atacama Desert during the Late Intermediate Period (AD 900–1450). *American Journal of Physical Anthropology* 156: 374-387.
- Santana-Sagredo F, Hubbe M, Uribe M. 2015b. Isotopic Evidence for Marine Consumption and Mobility in the Atacama Desert (Quillagua, Northern Chile). *International Journal of Osteoarchaeology.* DOI: 10.1002/OA.2437.
- Santana-Sagredo F, Uribe, M, Herrera MJ, Retamal R, Flores S. 2015c. Dieatry practices in ancient populations form northern Chile during the transition to agriculture (Tarapacá region, 1000 BC-AD 900). *American Journal of Physical Anthropology* 158: 751-758
- Santoro CM, Romero AG, Standen VG. 2003. Interacción social en los Períodos Intermedio Tardío y Tardío, Valle de Lluta, Norte de Chile. Taller Andino del Instituto de Investigaciones Andinas Cajamarca, Perú. Instituto de Estudios Peruanos.
- Santoro CM, Romero AG, Standen VG, Torres, A. 2004. Continuidad y cambio en las comunidades locales, Períodos Intermedio Tardío y Tardío, Valles Occidentales del área Centro Sur Andina. *Chungará*. Volumen Especial: 235-247.
- Schwarcz HP, Dupras T, Fairgrieve S. 1999. ^{15}N Enrichment in the Sahara: In Search of a Global Relationship. *Journal of Archaeological Science* 26: 629–636.
- Sealy J, Armstrong R, Schrire C. 1995. Beyond lifetime averages: tracing life histories through isotopic analysis of different calficied tissues from archaeological human skeletons. *Antiquity* 69: 290-300.
- Sharp, Z. 2007. *Principles of Stable Isotope Geochemistry*. Pearson Prentice Hall Upper Saddle River: New Jersey.
- Schiappacasse V, CastroV, Niemeyer H. 1989. Los Desarrollos Regionales en el Norte Grande. In *Culturas de Chile, Prehistoria*, Hidalgo J, Schiappacasse V, Niemeyer H, Aldunate C, Solimano I (eds). Andrés Bello: Santiago; 181-220.

- Smith BN, Epstein S. 1971. Two Categories of $^{13}C/^{12}C$ Ratios for Higher Plants. Plant Physiol 47: 380–384
- Schoeninger M, DeNiro M. 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* 48: 625–639
- Schulting, R.J. et al. 2014. Freshwater reservoir offsets investigated through paired human-faunal 14C dating and stable carbon and nitrogen isotope analysis at Lake Baikal, Siberia. *Radiocarbon* 56: 991–1008.
- Schulting, R.J. et al. 2015. Highly variable freshwater reservoir offsets found along the Upper Lena watershed, Cis-Baikal, south-east Siberia. *Radiocarbon* 57(4): DOI:10.2458/azu_rc.57.18458
- Schwarcz HP, Schoeninger MJ. 1991. Stable isotope analyses in human nutritional ecology. *American Journal of Physical Anthropology* 34: 283-321.
- Smith J. 2005. Climate change and agropastoral sustainability in the Shashe/ Limpopo river basin from AD 900. Johannesburg: University of Witwatersrand
- Siefeld WK, Vargas M. 1996. Composición y estructura de la ictiofauna demersal en la zona norte de Chile. *Investigaciones Marinas* 24: 3-17
- Snoeck C, Pouncett J, Ramsey G, Meighan IG, Mattielli N, Goderis S, Lee-Thorp JA, Schulting RJ. 2016. Mobility during the Neolithic and Bronze Age in Northern Ireland Explored Using Strontium Isotope Analysis of Cremated Human Bone. *American Journal of Physical Anthropology*. DOI: 10.1002/ajpa.22977
- Sokal R, Rohlf F. 1995. *Biometry*. W.H. Freeman: New York
- Sponheimer M. 1999. *Isotopic paleoecology of the Makapansgat limeworks fauna*. New Jersey: The State University of New Jersey
- Sponheimer M, Robinson T, Roeder A, Hammer J, Passey B, West A, Cerling T, Dearing D, Ehleringer J. 2003. Nitrogen isotopes in mammalian herbivores: Hair $\delta^{15}N$ values from a controlled feeding study. *International Journal of Osteoarchaeology* 13: 80-87
- Suess, HE. 1995. Radiocarbon concentration in modern wood. *Science* 122: 415-417
- Szpak P, Millaire J, White C, Longstaffe, F. 2012. Influence of seabird guano and camelid dung fertilization on the nitrogen isotopic composition of field-grown maize (Zea mays). *Journal of Archaeological Science* 39, 3721-3740
- Szpak P, White CD, Longstaffe FJ, Millaire JF, Vásquez S. 2013. Carbon and Nitrogen Isotopic Survey of Northern Peruvian Plants: Baselines for Palaeodietary and Paleoecological Studies. *Plos One* 8: e53763 1-28

- Thiel et al. 2007. The Humboldt Current System of northern and central chile. Oceanography and Marine Biology: An Annual Review 45: 195-344
- Tieszen L, Chapman M. 1992. Carbon and Nitrogen isotopic status of the major marine and terrestrial resources in the Atacama Desert of Northern Chile. In *Proceedings of the First World Congress on Mummy Studies*. Museo Arqueológico y Etnográfico de Tenerife: Cabildo de Tenerife; 409-426
- Tieszen L, Iversen E, Matzner S. 1992. Dietary reconstruction based or carbon, nitrogen and sulfur stable isotopes in the Atacama desert, Northern Chile. In *Proceedings of the First World Congress on Mummy Studies*. Museo Arqueológico y Etnográfico de Tenerife; Cabildo de Tenerife, 427-441
- Tieszen L, Fagre T. 1993. Effect of diet quality and composition on the isotopic composition of respiratory CO_2, bone collagen, bioapatite, and soft tissues. In *Prehistoric human bone-archaeology at the molecular level*. Lambert J, Grupe G, (eds.) Springer-Verlag: Berlin, 125-155
- Tomczak P. 2003. Prehistoric diet and socioeconomic relationships within the Osmore valley of southern Peru. *Journal of Anthropological Archaeology* 22: 262-278
- Torres-Rouff C. 2007. La deformación craneana en San Pedro de Atacama. *Estudios Atacameños* 33: 25-38
- Torres-Rouff C, Pestle W, Gallardo F. 2012. Eating fish in the driest desert in the world: Osteological and biogeochemical analyses of human skeletal remains from the San Salvador Cemetery, North Chile. *Latin American Antiquity* 23: 51-69
- Torres-Rouff C, Hubbe M. 2013. The sequence of human occupation in the Atacama Oases, Chile: A radiocarbon chronology based on human skeletal remains. *Latin American Antiquity* 24: 330-344.
- Torres-Rouff C, Knudson KJ, Pestle WJ, Stovel EM. 2015. Tiwanaku influence and social inequality: A bioarchaeological, biogeochemical, and contextual analysis of the Larache cemetery, San Pedro de Atacama, Northern Chile. *American Journal of Physical Anthropology* 158: 592-606.
- Torres-Rouff C, Kndson K, Pestle WJ, Stovel EM. 2015. Tiwanaku influence and social inequality: A bioarchaeological, biogeochemical, and contextual analysis of the Larache cemetery, San Pedro de Atacama, Northern Chile. *American Journal of Physical Anthropology* 158: 592-606.
- Troll C. 1958. *Las culturas superiores andinas y el medio geográfico*. Instituto de Geografía, Universidad de San Marcos: Lima

- Turner BL, Kamenov GD, Kingston JD, Armelagos GJ. 2009. Insights into immigration social class at Machu Picchu, Peru based on oxygen, strontium, and lead isotopic analysis. Journal of Archeological Science 36: 317-332.
- Turner BL, Kingston JD, Armelagos GJ. 2010. Variation in dietary histories among the immigrants of Machu Picchu: Carbon and nitrogen isotope evidence. *Chungará* 42: 515-534.
- Uribe M, Adán L. 2004. Evolución social a través de la prehistoria tardía de Pica-Tarapacá (Norte Grande de Chile). Informe FONDECYT 1030923: 1-16.
- Uribe M, Adán L, Agüero C. 2004. Arqueología de los períodos Intermedio Tardío y Tardío de San Pedro de Atacama y su relación con la cuenca del río Loa. *Chungará* 36: 943-956
- Uribe M., 2006. Acerca de complejidad, desigualdad social y el complejo cultural Pica-Tarapacá en los Andes Centro-Sur (1000-1450 d.C.). *Estudios Atacameños* 31: 91-114.
- Uribe, M. et al. 2007. La cerámica prehispánica tardía de Tarapacá, sus valles interiores y costa desértica, Norte de Chile (CA. 900-1450 D.C.): Una propuesta tipológica y cronológica. *Chungará* 39: 143-170.
- Uribe M. 2012. La prehistoria de Atacama. In: *Atacama*. Aldunate, C (eds.). Museo Chileno de Arte Precolombino: Santiago, 54-109.
- Uribe M, Santana-Sagredo F, Maturana A, Flores S, Agüero C. 2016. San Pedro de Atacama y la cuestión Tiwanaku en el norte de Chile: Impresiones a partir de un clásico estudio ceramic y la evidencia bioarqueológica actual. *Chungará* 48: 173-198.
- Vaiglova P. 2014. An integrated stable isotope study of plants and animals from Kouphovouno, southern Greece: a new look at Neolithic farming. *Journal of Archaeological Science* 42: 201-215.
- van Buren M. 1996. Rethinking the Vertical Archipelago: Ethnicity, exchange, and history in the South Central Andes. *American Anthropologist* 98: 338-351.
- van der Merwe NJ, Vogel JC. 1978. ^{13}Content of human collagen as a measure of prehistoric diet in woodland North America. *Nature* 276: 815-816.
- Vásquez J, Camus P, Ojeda P. 1998. Diversidad, estructura y funcionamiento de ecosistemas costeros rocosos del norte de Chile. *Revista Chilena de Historia Natural* 71: 479-499
- Veizer J. 1989. Strontium isotopes in seawater through time. *Annual Review Earth Planet Scienc*e 1: 141-167

- White C, Longstaffe F, Law K. 2004a. Exploring the effects of environment, physiology and diet on oxygen isotope radios in ancient Nubian bones and teeth. *Journal of Archeological Science* 31: 233-250
- White C, Spence M, Longstaffe F, Law K. 2004b. Demography and ethnic continuity in the Tlailotlacan enclave of Teotihuacan: the evidence from stable oxygen isotopes. *Journal of Anthropological Archaeology* 23: 385-403
- Williams JS, Katzenberg AM. 2012. Seasonal fluctuations in diet and death during the late horizon: a stable isotopic analysis of hair and nail from the central coast of Peru. *Journal of Archaeological Science* 39: 41-57
- Vergara L. 1901. Nuevas mediciones en trece cráneos antiguos de Aimaraes (Huacas de Quillagua). *Revista Chilena de Historia Natural* 5: 125-136
- Vergara L. 1905. Cráneos de paredes gruesas (nuevas investigaciones en 63 cráneos de Quillagua y algunos de la costa). *Revista Chilena de Historia Natural* 9: 172-190
- Yacobacio HD, Morales MR, Samec CT. 2009. Towards an isotopic ecology of herbivory in the Puna ecosystem: new results and patterns in Lama glama. *International Journal of Osteoarchaeology* 19: 144-155
- Yacobaccio HD, Samec CD, Catá MP. 2010. Isótopos estables y zooarqueología de camélidos en contextos pastoriles de la puna (Jujuy, Argentina). In *Zooarqueología a principios del siglo XXI. Aportes teóricos, metodológicos y casos de estudio*. Gutiérrez MA et al (eds). Editorial del Espinillo: Buenos Aires, 77-86
- Yesner D, Figuerero Torres M, Guichon R, Borrero L. 2003. Stable isotope analysis of human bone and etnohistoric subsistence patterns in Tierra del Fuego. *Journal of Anthropological Archaeology* 22: 279-291
- Zlatar V. 1984. *Cementerio Prehispánico Pica-8*. Antofagasta: Universidad de Antofagasta

Appendix

4.1 Carbon and nitrogen isotopes values for archaeological and modern plants and animals

4.1.1. Archaeological plants

Site	Species	Plant segment	$\delta^{13}C$	$\delta^{15}N$	%N	%C	Type	Period
Caserones	Zea mays	Cob	-10.6	13.3	1	43.9	Crop	Formative
Caserones	Zea mays	Grains	-9.8	3.4	1.8	38.2	Crop	Formative
Caserones	Zea mays	Cob	-10.3	11.3	0.7	41	Crop	Formative
Caserones	Zea mays	Cob	-10.1	6.9	0.9	43.1	Crop	Formative
Caserones	Zea mays	Cob	-10.4	8.3	0.5	43.3	Crop	Formative
Caserones	Zea mays	Cob	-10.2	9.9	0.4	41.7	Crop	Formative
Caserones	Zea mays	Cob	-10.9	14.7	0.8	38.1	Crop	Formative
Caserones	Zea mays	Grains	-9.7	12.2	1.9	42.3	Crop	Formative
Caserones	Zea mays	Cob	-10.5	6.6	1.6	39	Crop	Formative
Caserones	Zea mays	Cob	-10.2	9.1	0.6	42.7	Crop	Formative
Caserones	Zea mays	Cob	-10.1	14.4	1	38.4	Crop	Formative
Caserones	Amaranthus sp	Seeds	-11.1	8.4	2.3	39	Crop	Formative
Caserones	Lagenaria sp	Skin	-23.6	12.8	0.6	36.7	Crop	Formative
Pircas	Zea mays	Cob	-11.2	6.2	0.8	44	Crop	Formative
Pircas	Zea mays	Cob	-11.6	7.7	1.3	42.7	Crop	Formative
Pircas	Zea mays	Cob	-12.6	9.8	0.7	40.7	Crop	Formative
Pircas	Zea mays	Cob	-12.8	6.2	0.5	40.5	Crop	Formative
Pircas	Zea mays	Cob	-12.8	1.8	0.8	33.1	Crop	Formative
Pircas	Zea mays	Cob	-9.8	2.3	0.6	43.8	Crop	Formative
Pircas	Zea mays	Cob	-9	2.6	0.4	40.2	Crop	Formative
Tana Sur	Zea mays	Cob	-10.4	16.9	0.4	34	Crop	Formative
Tana Sur	Zea mays	Cob	-10.1	14.8	0.8	38.7	Crop	Formative
Tana Sur	Zea mays	Cob	-10.2	14	0.8	38.3	Crop	Formative
Tana Sur	Zea mays	Cob	-10.2	14.2	0.5	34	Crop	Formative
Tana Norte	Zea mays	Grains	-9.8	5.1	2	41	Crop	Formative
Tana Norte	Zea mays	Grains	-9.6	5	2.6	41	Crop	Formative
Tana Norte	Zea mays	Cob	-10.1	7.7	0.7	41.5	Crop	Formative
Tana Norte	Zea mays	Cob	-10	13.2	1.1	44.2	Crop	Formative
Solcor	Zea mays	Cob	-12.5	21.5	3.3	45.5	Crop	Middle Period
Bajo Molle 1	Lagenaria sp	Skin	-20.9	19	2	38.9	Crop	LIP
Bajo Molle 1	Zea mays	Grains	-10	22.1	1.4	42.1	Crop	LIP
Chomache 1	Lagenaria sp	Skin	-23.5	28.3	1.4	43.4	Crop	LIP
Chomache 1	Chenopodium quinoa	Seeds	-19.8	28.5	1.1	44.4	Crop	LIP
Los Verdes 9	Zea mays	Grains	-9.9	37	1.8	42.6	Crop	LIP
Patillos	Zea mays	Grains	-9.7	22.1	2	40.1	Crop	LIP
Patillos	Zea mays	Grains	-9.5	16.4	2.2	43	Crop	LIP
Patillos	Capsicum sp	Pod and seeds	-20.5	23.4	3.8	45.4	Crop	LIP

Pisagua 5	Zea mays	Grains	-9.8	22.5	1.5	41	Crop	LIP
Quillagua	Zea mays	Grains	-10.9	5.7	2.1	35	Crop	LIP
Quillagua	Zea mays	Cob	-10.4	18.1	2.7	42.9	Crop	LIP
Quillagua	Zea mays	Cob	-11.6	17.4	1.6	35.7	Crop	LIP
Quillagua	Zea mays	Cob	-12.8	21.3	2.6	43.7	Crop	LIP
Toconce	Zea mays	Cob	-11.3	9.1	1.1	40.3	Crop	LIP
Tarapaca Viejo	Zea mays	Cob	-10.9	18.8	0.7	30.7	Crop	LIP Late Period
Tarapaca Viejo	Zea mays	Cob	-11.3	27.3	1.1	30.7	Crop	LIP Late Period
Tarapaca Viejo	Zea mays	Cob	-10.5	18.5	0.8	21.2	Crop	LIP Late Period
Tarapaca Viejo	Zea mays	Cob	-10.9	16.6	1.5	44	Crop	LIP Late Period
Tarapaca Viejo	Zea mays	Grains	-10.1	8.3	2.5	42.5	Crop	LIP Late Period
Tarapaca Viejo	Zea mays	Grains	-9.7	19.4	1.8	39.8	Crop	LIP Late Period
Tarapaca Viejo	Zea mays	Cob	-10.6	21.1	1.2	43.5	Crop	LIP Late Period
Tarapaca Viejo	Zea mays	Cob	-10.1	21.2	1.6	40.2	Crop	LIP Late Period
Tarapaca Viejo	Zea mays	Cob	-12.7	25.7	1.7	38.7	Crop	LIP Late Period
Tarapaca Viejo	Zea mays	Cob	-10.9	22.6	1.3	42.1	Crop	LIP Late Period
Tarapaca Viejo	Zea mays	Cob	-10.7	25.7	0.9	43.1	Crop	LIP Late Period
Tarapaca Viejo	Zea mays	Cob	-9.8	31.2	1	43	Crop	LIP Late Period
Tarapaca Viejo	Zea mays	Cob	-9.9	19.5	1	44.6	Crop	LIP Late Period
Tarapaca Viejo	Lagenaria sp	Skin	-20.9	22.9	0.7	43.5	Crop	LIP Late Period
Caserones	Prosopis	Pod and seeds	-22.1	6.3	1.9	38	Fruit	Formative
Caserones	Prosopis	Pod and seeds	-20.3	11.1	2.2	39.6	Fruit	Formative
Caserones	Prosopis	Pod and seeds	-21.4	11.4	2.2	39.5	Fruit	Formative
Guatacondo 1	Prosopis	Pod and seeds	-22.4	5.8	3	35.8	Fruit	Formative
Guatacondo 1	Prosopis	Pod and seeds	-23.9	8	2	39	Fruit	Formative
Pircas	Prosopis	Pod and seeds	-24.3	-0.2	2.4	43.9	Fruit	Formative
Pircas	Prosopis	Pod and seeds	-22.5	3	1.7	43.9	Fruit	Formative
Pircas	Prosopis	Pod and seeds	-21.6	8.1	0.9	42	Fruit	Formative
Pircas	Prosopis	Pod and seeds	-21.6	8.8	2.7	40.1	Fruit	Formative
Tana Sur	Prosopis	Pod and seeds	-24.1	8.5	3.7	42.4	Fruit	Formative
Bajo Molle 1	Prosopis	Pod and seeds	-20	17.9	2.2	30.1	Fruit	LIP
Chomache 1	Prosopis	Pod and seeds	-19.8	26.4	0.9	38.9	Fruit	LIP
Quillagua La Capilla	Prosopis	Pod and seeds	-23.1	11.9	3.2	32.9	Fruit	LIP
Quitor 6	Prosopis	Cob	-22.2	20.6	5	41.4	Fruit	LIP
Tarapaca Viejo	Prosopis	Pod and seeds	-21.5	13.2	1.4	42	Fruit	LIP Late Period
Tarapaca Viejo	Prosopis	Pod and seeds	-22.5	13.2	1.9	40.6	Fruit	LIP Late Period

4.1.2. Modern Plants

Species	Location	Altitude	Pathway	Type	$\delta^{13}C$	$\delta^{15}N$	%C	%N
Festuca chrysophylla	Salar de Ascotan	3800	C3	Wild	-27.2	-9.5	42.5	0.6
Festuca chrysophylla	Salar de Ascotan	3800	C3	Wild	-25.4	-6.2	44.0	0.3
Festuca chrysophylla	Salar de Ascotan	3800	C3	Wild	-23.7	-3.0	46.0	0.3
Senecio eriophyton	La Poruñita	3700	C3	Wild	-22.4	5.2	46.3	1
Acantholippia deserticola	La Poruñita	3700	C3	Wild	-24.8	5.1	47.3	1.2
Indeterminate	La Poruñita	3700	C3	Wild	-24.0	-3.8	48.2	1.1
Indeterminate	La Poruñita	3700	C3	Wild	-23.2	-5.7	42.9	1.4
Acantholippia deserticola	La Poruñita	3700	C3	Wild	-25.8	2.5	40.2	0.9
Festuca chrysophylla	La Poruñita	3700	C3	Wild	-23.7	-1.7	43.2	0.5
Acantholippia deserticola	La Poruñita	3700	C3	Wild	-25.0	3.9	45.5	1.3
Senecio eriophyton	Salar de Ascotan	3800	C3	Wild	-21.1	3.8	41.9	1.2
Indeterminate	Poruña	3500	C3	Wild	-21.5	-0.8	48.0	1.1
Acantholippia deserticola	Ojo de Turi	3100	C3	Wild	-27.0	5.4	44.9	0.9
Senecio eriophyton	Topaín	3180	C3	Wild	-22.7	6.9	42.2	1.4
Indeterminate	Ojo de Turi	3100	C3	Wild	-26.3	7.3	44.1	1.6
Acantholippia deserticola	Ojo de Turi	3100	C3	Wild	-26.8	7.9	46.3	1.3
Acantholippia deserticola	Caspana	3300	C3	Wild	-24.9	1.5	32.5	1.5
Acantholippia deserticola	Caspana	3300	C3	Wild	-25.0	5.2	41.0	1.2
Acantholippia deserticola	Caspana	3300	C3	Wild	-25.2	2.6	42.5	0.9
Acantholippia deserticola	Talabre	3600	C3	Wild	-23.8	5.5	42.0	1.3
Indeterminate	Laguna Miscanti	4200	C3	Wild	-25.8	2.2	43.3	0.7
Indeterminate	Laguna Miscanti	4200	C3	Wild	-21.9	5.6	43.0	1.8
Festuca chrysophylla	Laguna Miñiques	4200	C3	Wild	-23.9	-1.2	46.0	0.7
Indeterminate	Paso Sico	4100	C3	Wild	-27.2	2.4	46.1	0.8
Festuca chrysophylla	Paso Sico	4100	C3	Wild	-24.6	-1.4	45.1	0.3
Festuca chrysophylla	Paso Sico	4100	C3	Wild	-23.7	1.2	43.2	0.6
Festuca chrysophylla	El Laco	4500	C3	Wild	-25.0	0.4	51.4	0.3
Indeterminate	El Laco	4500	C3	Wild	-27.8	1.5	54.0	1.9
Festuca chrysophylla	Sairecabur	4400	C3	Wild	-24.9	-6.4	49.0	0.8
Festuca chrysophylla	Sairecabur	4400	C3	Wild	-24.4	-5.3	41.4	0.3
Indeterminate	Volcan Tilocalar	3075	C3	Wild	-22.5	-1.4	43.6	1.9
Acantholippia deserticola	Volcan Tilocalar	3075	C3	Wild	-23.4	4.8	42.1	2.0
Indeterminate	Volcan Tilocalar	3075	C3	Wild	-22.7	-2.7	44.6	1.4
Geoffrea decorticans	San Pedro de Atacama	2450	C3	Wild	-25.8	-2.0	46.7	1.5
Geoffrea decorticans	San Pedro de Atacama	2450	C3	Wild	-26.1	-3.8	40.5	1.9
Geoffrea decorticans	San Pedro de Atacama	2450	C3	Wild	-26.0	-0.6	41.6	1.0
Citrus sinensis	50 km south to Pica	1100	C3	Crop	-24.3	5.2	48.0	3.1

Schinus molle	Matilla	1175	C3	Wild	-28.6	0.6	41.6	3.5
Prosopis tamarugo	Pintados	1015	C3	Wild	-27.6	-4.3	43.4	3.2
Prosopis tamarugo	Pintados	1015	C3	Wild	-25.8	-0.7	47.3	1.8
Prosopis tamarugo	La Huayca	990	C3	Wild	-28.2	-4.1	47.5	3.6
Prosopis tamarugo	La Huayca	990	C3	Wild	-28.4	-2.4	42.4	1.9
Schinus molle	La Tirana	1010	C3	Wild	-24.6	-0.9	41.6	3.9
Prosopis algarrobo	La Tirana	2450	C3	Wild	-25.8	-0.6	48.6	1.3
Prosopis algarrobo	La Tirana	2450	C3	Wild	-25.7	-1.5	43.4	1.0
Atriplex sp.	Colada de Volcan San Pedro	3600	C4	Wild	-14.0	5.4	44.3	1.9
Atriplex sp.	Poruña	3500	C4	Wild	-16.2	3.5	43.1	1.5
Atriplex sp.	Poruña	3500	C4	Wild	-14.3	7.6	43.2	1.8
Atriplex atacamensis	50 km south to Pica	1100	C4	Wild	-15.6	2.4	46.2	0.8
Atriplex atacamensis	50 km south to Pica	1100	C4	Wild	-14.2	6.6	41.0	1.5
Atriplex atacamensis	Pintados	1015	C4	Wild	-13.8	7.7	44.0	0.7

4.1.3 Archaeological and modern animals

Site	Animal	$\delta^{13}C$	$\delta^{15}N$	C/N	%C	%N
Cañamo 15B	Fish	-12.3	21.4	3.2	12.6	41.2
Pisagua 5	Fish	-14.2	18.3	3.1	15.2	40.3
Pisagua 5	Fish	-11.3	19.2	3.2	16.1	41.0
Chomache 1	Fish	-13.5	21.8	3.1	15.1	40.5
Tarapacá Viejo	Fish	-11.5	17.0	3.2	14.6	42.0
Chomache 1	Fish	-14.7	22.0	3.4	15.4	41.6
Chomache 1	Fish	-12.1	22.4	3.1	14.9	40.0
Chomache 1	Fish	-13.7	17.3	3.2	14.9	40.6
Chomache 1	Fish	-13.4	22.5	3.2	15.1	40.5
Quillagua	Fish	-13.4	17.3	3.4	15.1	42.0
Pisagua 5	Fish	-11.7	22.5	3.2	13.0	40.2
Cañamo	Seal	-12.2	20.6	3.5	13.8	37.8
Patache	Seal	-12.1	19.5	3.4	14.0	39.0
Modern Iquique	Pelican	-12.4	17.7	3.2	14.3	42.1
Modern Iquique	Pelican	-12.5	17.4	3.3	13.0	40.4
Modern Iquique	Pelican	-14.2	19.6	3.2	14.0	41.3
Chomache 1	Marine bird	-12.8	16.9	3.2	14.9	40.6
Chomache 1	Marine bird	-11.2	15.7	3.4	14.5	41.2
Tarapacá Viejo	Camelid	-14.3	10.3	3.2	14.2	38.6
Tarapacá Viejo	Camelid	-17.6	7.9	3.2	14.5	38.7
Tarapacá Viejo	Camelid	-17.0	9.9	3.2	14.9	39.9
Tarapacá Viejo	Camelid	-13.4	14.2	3.5	14.6	40.2
Tarapacá Viejo	Camelid	-18.0	6.0	3.2	12.2	33.9
Quitor 6	Camelid	-10.6	6.7	3.2	14.0	37.6
Quitor 6	Camelid	-9.1	7.0	3.2	13.0	36.1
Quitor 6	Camelid	-11.1	6.4	3.4	14.7	39.5
Toconce 02TO21	Camelid	-17.1	5.2	3.1	13.2	35.7

Los Morros 1	Camelid	-16.4	9.3	3.1	14.6	39.9
Solcor	Camelid	-12.2	8.6	3.3	14.8	41.1
Iquique	Dog	-17.3	11.9	3.2	14.7	40.3
Tarapacá Viejo	Dog	-17.2	6.2	3.2	15.2	41.5
Tarapacá Viejo	Dog	-16.9	15.4	3.1	12.4	41.4
Toconce	Rodent	-17.9	5.6	3.1	14.3	42.1
Toconce 02TO21	Rodent	-15.7	6.3	3.1	12.4	41.0
Iquique	Monkey	-15.7	13.2	3.2	15.2	42.0

5.1 Carbon and nitrogen isotope values for human remains

5.1.1 Carbon and nitrogen isotope values on bone collagen

Site	Sex	Location	Sample name	δ13C	δ15N	C/N	C%	%N
Caleta Huelen 12	M	Tarapaca Coast	CH12 PIT	-12.4	25.3	3.2	45.5	16.8
Caleta Huelen 11	F	Tarapaca Coast	CH 11 PIT FEM	-11.4	19.0	3.1	39.8	14.6
Caleta Huelen 11	M	Tarapaca Coast	CH11 PIT MASC	-13.0	25.4	3.1	35.1	12.7
Caletan Huelen 12	F	Tarapaca Coast	CH12 PIT FEM	-12.4	25.3	3.1	41.8	15.4
Pisagua-Uhle	M	Tarapaca Coast	PIS 255	-11.4	26.6	3.3	44.2	15.8
Pisagua-Uhle	U	Tarapaca Coast	Pis-279	-12.8	26.1	3.6	43.2	15.7
Pisagua-Uhle	M	Tarapaca Coast	PS 344	-11.3	25.0	3.3	46.8	17.0
Pisagua Gruta	U	Tarapaca Coast	PS1 GC.2	-11.9	27.4	3.3	42.8	15.7
Pisagua 5	U	Tarapaca Coast	PS5 C34	-9.2	21.9	3.2	41.6	14.9
Pisagua Hospital	U	Tarapaca Coast	Pis Hosp S6	-11.6	26.2	3.2	42.2	14.4
Pisagua Hospital	U	Tarapaca Coast	Pis Hosp S62	-12.1	26.1	3.2	38.8	13.9
Los Verdes 5	M	Tarapaca Coast	LV5_C243	-13.7	24.8	3.3	43.7	15.7
Bajo Molle Edificio Armada (Rescate CM)	M	Tarapaca Coast	BM C130	-11.3	24.4	3.3	36.8	12.9
Iquique-Calle Alessandri	M	Tarapaca Coast	Ca Alessandri C26	-9.7	26.8	3.2	41.3	12.2
Tarapaca pueblo	M	Tarapaca Inland	Resc Tar M1	-10.2	15.0	3.2	37.6	12.1
Tarapaca pueblo salvataje	F	Tarapaca Inland	SLT C121	-13.6	13.9	3.2	37.6	12.9
Pica 37	F	Tarapaca Inland	PICA 37 C2	-15.8	12.6	3.4	36.6	12.3
Pica 8	M	Tarapaca Inland	P8 B0414	-9.2	15.5	3.6	31.4	11.4

Pica 8	F	Tarapaca Inland	P8 B0422	-8.8	22.9	3.6	41.1	13.5
Pica 8	F	Tarapaca Inland	P8 B0433	-9.9	16.0	3.2	38.7	14.1
Pica 8	F	Tarapaca Inland	P8 B0438	-8.7	21.8	3.5	38.2	13.6
Pica 8	F	Tarapaca Inland	P8 B0442	-8.6	15.3	3.2	38.9	13.9
Pica 8	M	Tarapaca Inland	P8 B0444	-10.0	15.4	3.4	41.3	13.3
Pica 8	M	Tarapaca Inland	P8 B0449	-9.5	13.3	3.5	39.9	14.2
Pica 8	F	Tarapaca Inland	P8 B0451	-8.7	17.3	3.3	39.8	14.1
Pica 8	M	Tarapaca Inland	P8 B0455	-7.9	22.0	3.3	40.5	15.1
Pica 8	M	Tarapaca Inland	P8 B0476	-10.1	24.1	3.3	34.5	11.9
Pica 8	F	Tarapaca Inland	P8 B0478	-12.3	24.2	3.4	34.9	12.3
Pica 8	U	Tarapaca Inland	P8 B0498	-10.3	20.3	3.5	41.8	15.1
Pica 8	M	Tarapaca Inland	P8 B0796	-9.3	15.2	3.2	38.0	13.5
Auto Club	U	Antofagasta	AC 4631A	-12.1	24.6	3.4	33.8	12.5
Auto Club	F	Antofagasta	AC-4628.A	-11.4	25.7	3.2	37.7	13.7
Auto Club	M	Antofagasta	AC 4638.c1	-12.0	26.1	3.3	42.8	15.0
Auto Club	M	Antofagasta	AC-4641	-11.8	25.7	3.3	42.5	14.9
Auto Club	U	Antofagasta	AC-5052B	-11.3	25.1	3.2	37.3	13.4
El Vertedero	M	Antofagasta	EVC1	-12.0	25.5	3.2	45.1	14.3
Quitor 6	F	Atacama-Alto Loa	Q6T30	-13.6	11.1	3.3	40.9	14.4
Quitor 6	F	Atacama-Alto Loa	Q6T40	-15.0	11.4	3.6	43.0	15.0
Quitor 6	M	Atacama-Alto Loa	Q6T51	-13.7	11.6	3.3	38.1	13.0
Catarpe 1	M	Atacama-Alto Loa	CAT1-764	-12.9	12.9	3.2	42.0	15.0
Catarpe 1	F	Atacama-Alto Loa	CAT1-763	-13.6	11.4	3.4	44.3	15.8
Catarpe 1	F	Atacama-Alto Loa	CAT1-2397	-13.7	12.1	3.3	43.2	15.7
Caspana Le Paige	F	Atacama-Alto Loa	Cas12	-12.2	14.8	3.3	46.8	17.0
Caspana Le Paige	F	Atacama-Alto Loa	CAS61	-11.6	14.2	3.3	42.8	15.7
Caspana Le Paige	F	Atacama-Alto Loa	Cas 66	-12.9	15.4	3.3	41.6	14.9
Toconce Le Paige	F	Atacama-Alto Loa	Toconce 76	-14.2	11.5	3.3	38.0	13.5
Toconao Oriente	F	Atacama-Alto Loa	TO T1	-15.1	10.9	3.6	40.3	14.2
Toconao Oriente	F	Atacama-	TO-2	-14.5	11.1	3.2	41.5	14.7

		Alto Loa						
Toconao Oriente	M	Atacama-Alto Loa	TO-4	-14.1	11.7	3.4	39.8	13.6
Toconao Oriente	M	Atacama-Alto Loa	TO-5	-14.9	10.8	3.3	40.7	15.0
Toconao Oriente	F	Atacama-Alto Loa	TO-6	-14.6	11.0	3.3	42.1	13.3
Toconao Oriente	F	Atacama-Alto Loa	TO-7	-14.4	11.2	3.2	41.0	12.7
Toconao Oriente	F	Atacama-Alto Loa	TO T8	-15.5	10.5	3.7	41.3	13.6
Toconao Oriente	M	Atacama-Alto Loa	TO-12	-13.2	12.7	3.2	37.8	12.9
Toconao Oriente	M	Atacama-Alto Loa	TO-14	-16.6	7.3	3.6	45.0	17.0
Toconao Oriente	F	Atacama-Alto Loa	TO-15	-14.6	13.6	3.4	41.2	15.0
Toconao Oriente	M	Atacama-Alto Loa	TO-16	-14.5	12.9	3.6	43.3	14.3

5.1.2 Carbon isotope values for bone apatite and tooth enamel

Site	Sex	Location	Sample name	Enamel $\delta^{13}C$	Bone $\delta^{13}C$
Caleta Huelen 12	M	Tarapaca Coast	CH12 PIT		-8.9
Caleta Huelen 11	F	Tarapaca Coast	CH 11 PIT FEM		-5.7
Caleta Huelen 11	M	Tarapaca Coast	CH11 PIT MASC		-9.1
Caletan Huelen 12	F	Tarapaca Coast	CH12 PIT FEM		-9.7
Pisagua-Uhle	M	Tarapaca Coast	PIS 255	-8.3	-9.8
Pisagua-Uhle	U	Tarapaca Coast	PSI 286	-7.3	-10.6
Pisagua-Uhle	M	Tarapaca Coast	PS 292	-8.0	
Pisagua-Uhle	F	Tarapaca Coast	PS 301	-8.6	
Pisagua-Uhle	M	Tarapaca Coast	PS 302	-12.9	
Pisagua-Uhle	M	Tarapaca Coast	PS 305	-7.5	
Pisagua-Uhle	F	Tarapaca Coast	PS 334	-8.0	
Pisagua-Uhle	M	Tarapaca Coast	PS 344	-5.9	
Pisagua Gruta	U	Tarapaca Coast	PS1 GC.1	-8.0	-9.5
Pisagua Gruta	U	Tarapaca Coast	PS1 GC.2	-7.5	-9.4

Pisagua Gruta	U	Tarapaca Coast	PS1 GC.3	-8.6	
Pisagua 5	U	Tarapaca Coast	PS5 C34	-3.0	-11.0
Pisagua Hospital	U	Tarapaca Coast	Pis Hosp S6		-10.1
Pisagua Hospital	U	Tarapaca Coast	Pis Hosp S62		-9.3
Los Verdes 1	U	Tarapaca Coast	LOS VERDES C77	-8.9	
Los Verdes 1	M	Tarapaca Coast	LOS VERDES 1 C333	-8.1	
Los Verdes 5	M	Tarapaca Coast	LV5_C243		-11.1
Patache Q	M	Tarapaca Coast	PATACHE Q7C2	-8.0	
Bajo Molle Edificio Armada (Rescate CM)	M	Tarapaca Coast	BM C130		-8.8
Bajo Molle 1	F	Tarapaca Coast	BM1 C153	-7.9	
Bajo Molle 1	U	Tarapaca Coast	BM1 C151	-4.8	
Bajo Molle Edificio Armada (Rescate CM)	M	Tarapaca Coast	BM1 C189	-3.3	
Iquique-Calle Alessandri	M	Tarapaca Coast	Ca Alessandri C26	-6.1	-6.5
Iquique-Calles Tarapacá con Labbe	U	Tarapaca Coast	Resc Tar Lab C175		-8.8
Tarapaca pueblo	M	Tarapaca Inland	Resc Tar M1		-6.1
Tarapaca pueblo salvataje	F	Tarapaca Inland	SLT C121		-11.2
Pica 37	F	Tarapaca Inland	PICA 37 C2	-9.2	-12.8
Pica 37	M	Tarapaca Inland	P37 C4		-13.3
Pica 8	F	Tarapaca Inland	P8 B0413	-2.04	
Pica 8	M	Tarapaca Inland	P8 B0414		-3.6
Pica 8	F	Tarapaca Inland	P8 B0419	-2.9	
Pica 8	F	Tarapaca Inland	P8 B0420	-11.4	
Pica 8	F	Tarapaca Inland	P8 B0421	-2.5	
Pica 8	F	Tarapaca Inland	P8 B0422		-4.1
Pica 8	F	Tarapaca Inland	P8 B0424	-8.5	
Pica 8	F	Tarapaca Inland	P8 B0426	-4.2	
Pica 8	M	Tarapaca Inland	P8 B0427	-11.5	
Pica 8	F	Tarapaca Inland	P8 B0428	-2.1	
Pica 8	M	Tarapaca Inland	P8 B0431	-6.2	
Pica 8	F	Tarapaca	P8 B0432	-4.0	

		Inland			
Pica 8	F	Tarapaca Inland	P8 B0433		-5.2
Pica 8	F	Tarapaca Inland	P8 B0438		-4.7
Pica 8	F	Tarapaca Inland	P8 B0439	-7.2	
Pica 8	M	Tarapaca Inland	P8 B0440	-0.6	
Pica 8	M	Tarapaca Inland	P8 B0441	0.7	
Pica 8	M	Tarapaca Inland	P8 B0444		-4.6
Pica 8	M	Tarapaca Inland	P8 B0447	-1.9	
Pica 8	M	Tarapaca Inland	P8 B0449		-4.4
Pica 8	F	Tarapaca Inland	P8 B0451		-3.9
Pica 8	F	Tarapaca Inland	P8 B0453	-11.1	
Pica 8	M	Tarapaca Inland	P8 B0455		-3.6
Pica 8	F	Tarapaca Inland	P8 B0463	-2.7	
Pica 8	F	Tarapaca Inland	P8 B0468	-3.0	
Pica 8	M	Tarapaca Inland	P8 B0471	-5.9	
Pica 8	F	Tarapaca Inland	P8 B0473	-5.0	
Pica 8	M	Tarapaca Inland	P8 B0476	-4.8	-4.4
Pica 8	F	Tarapaca Inland	P8 B0478	-9.0	-11.1
Pica 8	F	Tarapaca Inland	P8 B0483	-2.2	
Pica 8	F	Tarapaca Inland	P8 B0490	-4.4	
Pica 8	M	Tarapaca Inland	P8 B0493	-3	
Pica 8	U	Tarapaca Inland	P8 B0494	-4.2	
Pica 8	F	Tarapaca Inland	P8 B0495	-4.0	
Pica 8	U	Tarapaca Inland	P8 B0498		-8.7
Pica 8	M	Tarapaca Inland	P8 B0513	-7.5	
Pica 8	M	Tarapaca Inland	P8 B0796		-4.9
Quillagua-Cementerio Oriente	F	Tarapaca Inland	02QUI01 CTX3	-11.9	
Quillagua-Cementerio Oriente	M	Tarapaca Inland	02QUI01 CTX2	-11.3	
Auto Club	M	Antofagasta	AC 4627	-6.6	
Auto Club	U	Antofagasta	AC 4631A	-9.2	
Auto Club	F	Antofagasta	AC-4628.A		-8.4

Auto Club	M	Antofagasta	AC 4638.c1		-8.8
Auto Club	M	Antofagasta	AC-4641		-6.7
Auto Club	U	Antofagasta	AC-5052B		-8.2
El Vertedero	M	Antofagasta	EVC1	-8.8	-8.9
El Vertedero	F	Antofagasta	EV-3		-7.6
Quitor 6	M	Atacama-Alto Loa	Q6T07	-7.5	-9.9
Quitor 6	M	Atacama-Alto Loa	Q6T11	-9.8	
Quitor 6	F	Atacama-Alto Loa	Q6-21		-9.3
Quitor 6	F	Atacama-Alto Loa	Q6T30	-6.9	-8.2
Quitor 6	M	Atacama-Alto Loa	Q6T31	-6.6	
Quitor 6	F	Atacama-Alto Loa	Q6T34	-6.2	-8.5
Quitor 6	M	Atacama-Alto Loa	Q6T35	-8.7	
Quitor 6	F	Atacama-Alto Loa	Q6T40	-8.7	
Quitor 6	F	Atacama-Alto Loa	Q6T47	-9.1	
Quitor 6	M	Atacama-Alto Loa	Q6T51	-5.2	-7.6
Quitor 6	F	Atacama-Alto Loa	Q6T54	-2.1	-6.3
Catarpe 1	M	Atacama-Alto Loa	CAT1 885	-5.3	
Catarpe 1	M	Atacama-Alto Loa	CAT1 2396	-7.3	
Catarpe 1	M	Atacama-Alto Loa	CAT1 2406	-7.9	
Catarpe 1	M	Atacama-Alto Loa	CAT1 4849	-6.5	
Catarpe 1	F	Atacama-Alto Loa	CAT1-763		-7.4
Catarpe 1	F	Atacama-Alto Loa	CAT1-2397		-7.6
Caspana Le Paige	M	Atacama-Alto Loa	CAS 16	-4.5	
Toconce Le Paige	F	Atacama-Alto Loa	Toconce 76		-8.9
Toconce Le Paige	M	Atacama-Alto Loa	TOCONCE 87	-8.2	
Toconao Oriente	F	Atacama-Alto Loa	TO T1		-10.4
Toconao Oriente	F	Atacama-Alto Loa	TO-2		-10.5
Toconao Oriente	M	Atacama-Alto Loa	TO-3		-8.3
Toconao Oriente	M	Atacama-Alto Loa	TO-4		-8.7
Toconao Oriente	M	Atacama-Alto Loa	TO-5		-11.6
Toconao Oriente	F	Atacama-Alto Loa	TO-6		-10.0

Toconao Oriente	F	Atacama-Alto Loa	TO-7		-8.4
Toconao Oriente	F	Atacama-Alto Loa	TO T8		-10.2
Toconao Oriente	M	Atacama-Alto Loa	TO-T9		-8.4
Toconao Oriente	M	Atacama-Alto Loa	TO-T11 C1		-11.3
Toconao Oriente	M	Atacama-Alto Loa	TO-12		-10.0
Toconao Oriente	F	Atacama-Alto Loa	TO-13		-10.2
Toconao Oriente	M	Atacama-Alto Loa	TO-14		-9.7
Toconao Oriente	F	Atacama-Alto Loa	TO-15		-8.6
Toconao Oriente	M	Atacama-Alto Loa	TO-16		-9.1

Sample	Hair 1 d13C	Hair 1 d15N	C/N	Hair 2 d13C	Hair 2 d15N	C/N	Hair 3 d13C	Hair 3 d15N	C/N	Hair 4 d13C	Hair 4 d15N	C/N	Hair 5 d13C	Hair 5 d15N	C/N	Hair 6 d13C	Hair 6 15dN	C/N
P8 B0410	-11.1	25	3.6	-10.4	24.4	3.5	-10.4	23.7	3.5	-10.6	23.6	3.5	-10.1	24.5	3.6	-10.1	24.4	3.6
P8 B0413	-9.6	20.5	3.8	-9.5	20.1	3.6	-9.3	20.2	3.6	-9.1	20	3.5	-9	19.6	3.5	-9.3	19.4	3.6
P8 B0415	-10	13.3	3.8	-9.6	13.3	3.7	-9.2	13.5	3.7	-15.8	6.8	3.2	-9.5	13.8	3.7	-10.5	13.9	3.7
P8 B0419	-10.1	15.1	3.8	-9.9	14.7	3.6	-9.9	14.7	3.5	-9.9	14.8	3.6	-9.9	14.6	3.6	-9.6	14.3	3.5
P8 B0420	-11.2	22.3	3.7	-10.5	22.4	3.6	-10.2	21.6	3.6	-10.7	20.4	3.5	-11.6	19.2	3.6	-12.1	18.4	3.6
P8 B0421	-10.2	16.7	4	-11.1	16.5	3.9	-10.7	16.9	3.8	-10.4	16.8	3.8	-10.1	16.5	3.8	-10.2	16.9	3.8
P8 B0423	-12.3	19.5	3.5	-10.7	21.1	3.5	-10	22	3.5	-10.1	22.4	3.5	-10.6	22.3	3.5	-11.1	21.9	3.5
P8 B0424	-12.9	24.7	3.8	-12.7	24.4	3.7	-12.7	24.7	3.7	-13.4	25.6	3.8	-14.5	26.6	3.6	-14.1	25.6	3.6
P8 B0425	-12.6	13.7	3.9	-12.4	14.1	3.8	-12	13.6	3.8	-12.3	13.8	3.8	-12.2	14	3.8	-12.1	14	3.7
P8 B0427	-15.7	12.6	3.9	-15.9	12.6	3.8	-13.5	12.9	3.9	-14.4	12.9	3.8	-16.4	12.6	3.8	-16.7	13.1	3.8
P8 B0428	-11.5	15.1	3.8	-11.7	14.3	3.8	-11.8	13.2	3.7	-12.4	13.8	3.6	-12.4	14.6	3.7	-12.6	15	3.7
P8 B0430	-10.4	18.8	4	-10.2	18.9	3.9	-10.2	18.9	4	-10.1	18.6	3.8	-10.1	18.1	3.9	-10.1	18.1	3.9
P8 B0431	-15.3	16.1	4	-14.2	15.6	3.8	-15.1	15.1	3.8	-14.8	14.8	3.8	-18.5	7.9	3.2	-14.1	16.4	3.7
P8 B0432	-9.4	25.1	3.9	-9.2	25.3	3.9	-8.2	25.3	3.7	-7.9	24.7	3.5	missing	missing	missing	-9.3	25.3	3.8
P8 B0433	-10.6	17.8	3.5	-10	17.7	3.5	-10.5	17.5	3.5	-10.5	17.1	3.5	-10.7	16.9	3.5	-11.3	16.6	3.5
P8 B0435	-9.8	13.2	3.8	-9.2	13.4	3.7	-9	13.1	3.6	-9.3	12.6	3.7	-9.9	12.4	3.7	-10.7	12.6	3.7
P8 B0438	-8.3	23.1	3.6	-8.5	22.9	3.5	-8.7	22.4	3.5	-8.7	22.4	3.5	-8.7	22.9	3.5	-8.8	23.5	3.5
P8 B0439	-10.6	17.2	3.5	-10.5	17.4	3.5	-10.4	16.6	3.5	-10.5	16.2	3.5	-11.1	16.2	3.6	-11.2	17	3.6
P8 B0440	-10.6	16.3	3.5	-10.5	16.5	3.5	-11	16.2	3.5	-11.1	17.2	3.5	-10.8	17.4	3.4	-10.5	17.5	3.4
P8 B0441	-9.3	19.4	3.7	-9.9	19	3.7	-9.9	19.4	3.7	-9.7	20.6	3.7	-8.9	22.1	3.7	-8.7	22.3	3.8
P8 B0442	-11.2	13.1	3.6	-10.4	13.2	3.4	-9.9	12.7	3.4	-9.6	12.3	3.4	-9.7	12.1	3.4	-9.7	12.1	3.5
P8 B0447	-9.9	24	3.9	-9.2	23.8	3.8	-9.3	23.5	3.8	-9.5	22.9	3.8	-9.7	22.8	3.8	-9.7	22.6	3.8
P8 B0453	-10	19.6	3.5	-9.5	19.7	3.5	-8.9	19.8	3.5	-8.2	21.3	3.5	-8.2	22.3	3.5	-8.3	22.4	3.5
P8 B0460	-11	12.8	3.6	-11.4	12.8	3.6	-10.8	13.2	3.6	-10.1	12.9	3.6	-10	13.4	3.7	-10.2	12.7	3.7

P8 B0462	-10.1	13.9	3.8	-10	13.2	3.7	-10.4	13.3	3.7	-11.2	13.2	3.7	-11.7	12.7	3.7	-11.5	12.8	3.7
P8 B0463	-10.5	15.2	3.7	-10.3	15.6	3.6	-9.9	15.4	3.6	-10.3	15.8	3.6	-10.5	16.5	3.6	-10.5	16.3	3.5
P8 B0468	-9.2	22.7	3.8	-8.9	22.1	3.6	-9.3	22.3	3.6	-9.7	22.3	3.7	-9.2	22.1	3.7	-9.5	21.7	3.7
P8 B0469	-8.8	23.2	3.7	-8.7	23.1	3.7	-9.2	22.4	3.7	-9.5	22.4	3.7	-8.9	23.2	3.7	-8.9	23.1	3.7
P8 B0470	-10.3	14.9	3.9	-10.5	14.3	3.7	-11.4	13.8	3.6	-10.8	13.7	3.5	-11	14.1	3.5	-11.3	14.1	3.5
P8 B0476	-8.1	25.6	3.6	-8.2	25.6	3.6	-8.3	25.9	3.6	-8.4	25.9	3.6	-8.1	26	3.6	-8.1	26.2	3.6
P8 B0485	-8.9	20.6	4	-8.5	20.8	3.8	-8.9	20.8	4	-8.9	21.6	3.9	-9.3	21.5	3.8	missing	missing	missing
P8 B0493	-9.7	15.6	3.5	-11.2	15.9	3.5	-12.6	16.3	3.5	-11.4	15.8	3.5	-11.2	14.4	3.5	-12.7	12.6	3.5
P8 B0509	-16.1	19.9	3.8	-15.3	20.7	3.6	-14.1	23.6	3.5	-13.4	24.1	3.5	-14	24.2	3.5	-13.7	23.9	3.5
PIS 255A	-11.8	23.2	3.6	-11.8	23	3.7	-11.7	23.2	3.6	-11.7	23	3.7	-11.6	23	3.6	-11.7	23	3.6
PIS 259	-14	22	3.6	-14	21.5	3.6	-14.1	22	3.6	-13.8	22	3.6	-13.9	22	3.6	-14	21.6	3.7
BAJO MOLLE 1 5SE 153	-10.7	20.8	3.7	-10.3	18.5	3.6	-10.5	17.1	3.6	-10.4	16.1	3.6	-10.8	15.8	3.6	-11	15.1	3.6
PIS GRUTA C1	-12.6	26.5	3.5	-13	26.3	3.7	-12.7	26	3.6	-12.7	26.4	3.5	-12.5	26.1	3.6	-12.6	25.4	3.7
PIS 301	-13.9	23.8	3.8	-13.6	22.4	3.7	-13.7	22.1	3.7	-14	22.2	3.7	-14.4	22.2	3.8	-14.2	22	3.8
PATACHE 194	-14.2	25.4	3.9	-13.5	25.4	3.8	-13.1	25.3	3.8	-13	25.1	3.8	-13.6	25.6	3.7	-13.8	25.6	3.7
BAJO MOLLE EDIFICIO ARMADA 189	-9.5	14	3.7	-9.5	13.8	3.7	-9.6	13.9	3.7	-9.6	13.7	3.7	-9.6	13.6	3.8	-9.6	13.7	3.8
LOS VERDES A3 B	-15.4	19.4	3.8	-15.5	19.2	4	-15.2	19.6	3.8	-14.5	19.7	3.9	-13.8	20	3.9	-13.8	19.8	3.8

5.1.3 Carbon and nitrogen isotope values for hair segments(from 1 to 6 cms)

7.1 Oxygen isotope values on human bone apatite and tooth enamel

Site	Sex	Location	Sample name	Enamel $\delta^{18}O$	Bone δ18O
Caleta Huelen 12	M	Tarapaca Coast	CH12 PIT		-8.9
Caleta Huelen 11	F	Tarapaca Coast	CH 11 PIT FEM		-5.7
Caleta Huelen 11	M	Tarapaca Coast	CH11 PIT MASC		-9.1
Caletan Huelen 12	F	Tarapaca Coast	CH12 PIT FEM		-9.7
Pisagua-Uhle	M	Tarapaca Coast	PIS 255	-8.3	-9.8
Pisagua-Uhle	U	Tarapaca Coast	PSI 286	-7.3	-10.6
Pisagua-Uhle	M	Tarapaca Coast	PS 292	-8.0	
Pisagua-Uhle	F	Tarapaca Coast	PS 301	-8.6	
Pisagua-Uhle	M	Tarapaca Coast	PS 302	-12.9	
Pisagua-Uhle	M	Tarapaca Coast	PS 305	-7.5	
Pisagua-Uhle	F	Tarapaca Coast	PS 334	-8.0	
Pisagua-Uhle	M	Tarapaca Coast	PS 344	-5.9	
Pisagua Gruta	U	Tarapaca Coast	PS1 GC.1	-8.0	-9.5
Pisagua Gruta	U	Tarapaca Coast	PS1 GC.2	-7.5	-9.4
Pisagua Gruta	U	Tarapaca Coast	PS1 GC.3	-8.6	
Pisagua 5	U	Tarapaca Coast	PS5 C34	-3.0	-11.0
Pisagua Hospital	U	Tarapaca Coast	Pis Hosp S6		-10.1
Pisagua Hospital	U	Tarapaca Coast	Pis Hosp S62		-9.3
Los Verdes 1	U	Tarapaca Coast	LOS VERDES C77	-8.9	
Los Verdes 1	M	Tarapaca Coast	LOS VERDES 1 C333	-8.1	
Los Verdes 5	M	Tarapaca Coast	LV5_C243		-11.1
Patache Q	M	Tarapaca Coast	PATACHE Q7C2	-8.0	
Bajo Molle Edificio Armada (Rescate CM)	M	Tarapaca Coast	BM C130		-8.8
Bajo Molle 1	F	Tarapaca Coast	BM1 C153	-7.9	
Bajo Molle 1	U	Tarapaca Coast	BM1 C151	-4.8	
Bajo Molle Edificio Armada (Rescate CM)	M	Tarapaca Coast	BM1 C189	-3.3	
Iquique-Calle Alessandri	M	Tarapaca Coast	Ca Alessandri C26	-6.1	-6.5
Iquique-Calles Tarapacá con Labbe	U	Tarapaca Coast	Resc Tar Lab C175		-8.8

Tarapaca pueblo	M	Tarapaca Inland	Resc Tar M1		-6.1
Tarapaca pueblo salvataje	F	Tarapaca Inland	SLT C121		-11.2
Pica 37	F	Tarapaca Inland	PICA 37 C2	-9.2	-12.8
Pica 37	M	Tarapaca Inland	P37 C4		-13.3
Pica 8	F	Tarapaca Inland	P8 B0413	-2.04	
Pica 8	M	Tarapaca Inland	P8 B0414		-3.6
Pica 8	F	Tarapaca Inland	P8 B0419	-2.9	
Pica 8	F	Tarapaca Inland	P8 B0420	-11.4	
Pica 8	F	Tarapaca Inland	P8 B0421	-2.5	
Pica 8	F	Tarapaca Inland	P8 B0422		-4.1
Pica 8	F	Tarapaca Inland	P8 B0424	-8.5	
Pica 8	F	Tarapaca Inland	P8 B0426	-4.2	
Pica 8	M	Tarapaca Inland	P8 B0427	-11.5	
Pica 8	F	Tarapaca Inland	P8 B0428	-2.1	
Pica 8	M	Tarapaca Inland	P8 B0431	-6.2	
Pica 8	F	Tarapaca Inland	P8 B0432	-4.0	
Pica 8	F	Tarapaca Inland	P8 B0433		-5.2
Pica 8	F	Tarapaca Inland	P8 B0438		-4.7
Pica 8	F	Tarapaca Inland	P8 B0439	-7.2	
Pica 8	M	Tarapaca Inland	P8 B0440	-0.6	
Pica 8	M	Tarapaca Inland	P8 B0441	0.7	
Pica 8	M	Tarapaca Inland	P8 B0444		-4.6
Pica 8	M	Tarapaca Inland	P8 B0447	-1.9	
Pica 8	M	Tarapaca Inland	P8 B0449		-4.4
Pica 8	F	Tarapaca Inland	P8 B0451		-3.9
Pica 8	F	Tarapaca Inland	P8 B0453	-11.1	
Pica 8	M	Tarapaca Inland	P8 B0455		-3.6
Pica 8	F	Tarapaca Inland	P8 B0463	-2.7	
Pica 8	F	Tarapaca Inland	P8 B0468	-3.0	
Pica 8	M	Tarapaca	P8 B0471	-5.9	

		Inland			
Pica 8	F	Tarapaca Inland	P8 B0473	-5.0	
Pica 8	M	Tarapaca Inland	P8 B0476	-4.8	-4.4
Pica 8	F	Tarapaca Inland	P8 B0478	-9.0	-11.1
Pica 8	F	Tarapaca Inland	P8 B0483	-2.2	
Pica 8	F	Tarapaca Inland	P8 B0490	-4.4	
Pica 8	M	Tarapaca Inland	P8 B0493	-3	
Pica 8	U	Tarapaca Inland	P8 B0494	-4.2	
Pica 8	F	Tarapaca Inland	P8 B0495	-4.0	
Pica 8	U	Tarapaca Inland	P8 B0498		-8.7
Pica 8	M	Tarapaca Inland	P8 B0513	-7.5	
Pica 8	M	Tarapaca Inland	P8 B0796		-4.9
Quillagua-Cementerio Oriente	F	Tarapaca Inland	02QUI01 CTX3	-11.9	
Quillagua-Cementerio Oriente	M	Tarapaca Inland	02QUI01 CTX2	-11.3	
Auto Club	M	Antofagasta	AC 4627	-6.6	
Auto Club	U	Antofagasta	AC 4631A	-9.2	
Auto Club	F	Antofagasta	AC-4628.A		-8.4
Auto Club	M	Antofagasta	AC 4638.c1		-8.8
Auto Club	M	Antofagasta	AC-4641		-6.7
Auto Club	U	Antofagasta	AC-5052B		-8.2
El Vertedero	M	Antofagasta	EVC1	-8.8	-8.9
El Vertedero	F	Antofagasta	EV-3		-7.6
Quitor 6	M	Atacama-Alto Loa	Q6T07	-7.5	-9.9
Quitor 6	M	Atacama-Alto Loa	Q6T11	-9.8	
Quitor 6	F	Atacama-Alto Loa	Q6-21		-9.3
Quitor 6	F	Atacama-Alto Loa	Q6T30	-6.9	-8.2
Quitor 6	M	Atacama-Alto Loa	Q6T31	-6.6	
Quitor 6	F	Atacama-Alto Loa	Q6T34	-6.2	-8.5
Quitor 6	M	Atacama-Alto Loa	Q6T35	-8.7	
Quitor 6	F	Atacama-Alto Loa	Q6T40	-8.7	
Quitor 6	F	Atacama-Alto Loa	Q6T47	-9.1	
Quitor 6	M	Atacama-Alto Loa	Q6T51	-5.2	-7.6
Quitor 6	F	Atacama-Alto	Q6T54	-2.1	-6.3

		Loa			
Catarpe 1	M	Atacama-Alto Loa	CAT1 885	-5.3	
Catarpe 1	M	Atacama-Alto Loa	CAT1 2396	-7.3	
Catarpe 1	M	Atacama-Alto Loa	CAT1 2406	-7.9	
Catarpe 1	M	Atacama-Alto Loa	CAT1 4849	-6.5	
Catarpe 1	F	Atacama-Alto Loa	CAT1-763		-7.4
Catarpe 1	F	Atacama-Alto Loa	CAT1-2397		-7.6
Caspana Le Paige	M	Atacama-Alto Loa	CAS 16	-4.5	
Toconce Le Paige	F	Atacama-Alto Loa	Toconce 76		-8.9
Toconce Le Paige	M	Atacama-Alto Loa	Toconce 87	-8.2	
Toconao Oriente	F	Atacama-Alto Loa	TO T1		-10.4
Toconao Oriente	F	Atacama-Alto Loa	TO-2		-10.5
Toconao Oriente	M	Atacama-Alto Loa	TO-3		-8.3
Toconao Oriente	M	Atacama-Alto Loa	TO-4		-8.7
Toconao Oriente	M	Atacama-Alto Loa	TO-5		-11.6
Toconao Oriente	F	Atacama-Alto Loa	TO-6		-10.0
Toconao Oriente	F	Atacama-Alto Loa	TO-7		-8.4
Toconao Oriente	F	Atacama-Alto Loa	TO T8		-10.2
Toconao Oriente	M	Atacama-Alto Loa	TO-T9		-8.4
Toconao Oriente	M	Atacama-Alto Loa	TO-T11 C1		-11.3
Toconao Oriente	M	Atacama-Alto Loa	TO-12		-10.0
Toconao Oriente	F	Atacama-Alto Loa	TO-13		-10.2
Toconao Oriente	M	Atacama-Alto Loa	TO-14		-9.7
Toconao Oriente	F	Atacama-Alto Loa	TO-15		-8.6
Toconao Oriente	M	Atacama-Alto Loa	TO-16		-9.1