

Mid-Late Holocene Populations at the Fénix Archaeological Complex, Valparaíso Region of Central Chile: An Investigation into Diet and Mobility through Isotope and Elemental Analyses

by

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8 March 2019

DECLARATION OF CANDIDATE

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

Signed,

mildie

Bianca Waldie

12/11/2018

DECLARATION OF SUPERVISOR

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

Signed,

Associate Professor Amy Roberts

12/11/2018

DEDICATION

To my mother, Karen Craven (1964–2017).

ABSTRACT

This thesis examines the bone chemistry of mid-Archaic to Late Intermediate Period (c. 7000–550 BP) Chilean populations excavated from the Fénix Archaeological Complex at Quintero Bay in central Chile. Stable carbon, nitrogen and oxygen isotope analyses were used to assess changes and/or continuities in the diet and mobility of the Fénix populations, including, but not limited to, marine versus terrestrial resource use, the adoption of agricultural practices and population movement across the landscape. In addition, laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) was used to investigate a range of elemental concentrations, which can contribute dietary information (such as information on trophic level), and post-burial diagenesis within the sample set. A further six radiocarbon dates were also obtained in order to refine the chronological sequence at the Fénix Archaeological Complex.

Stable carbon, nitrogen and oxygen isotope results from skeletal material indicate that the population at the Fénix Archaeological Complex were consuming mixed resources (C₃ and C₄), with the addition of wild herbivores and marine resources from lower trophic levels, while travelling between the valleys and the coasts of central Chile. Elemental analyses of strontium, barium and calcium suggest that the population were consuming high trophic level terrestrial foods, with the contribution of marine resources. Furthermore, elemental analysis of uranium suggests limited post-burial diagenetic contamination, based on the low concentrations of this element in the skeletal samples analysed. Additional radiocarbon dates of between 5315–557 cal BP expanded the timeline for the Fénix Archaeological Complex allowing for a comprehensive refinement of the chronology of the site and clarification of relative dates in stratigraphically complex areas.

This research presents results for the largest single site sample set that has been undertaken for isotopic research in central Chile to date. As such, not only do these results allow a much deeper understanding of the complex formational history at the Fénix Archaeological Complex, but they also provide a significant set of data for research on coastal central Chilean populations during the mid-late Holocene.

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GLOSSARY / TRANSLATIONS

Agriculture – The cultivation of plants used to sustain and enhance human life.

Calcium Carbonate – A mineral composed of CaCO₃, which is a significant component of bone, adding strength to harden the framework.

Collagen – The fibrous protein constituent of bone, which creates a flexible framework for cartilage, tendon and other connective tissue.

Cordillera – The Spanish word for mountain range. Used frequently in the text to refer to the coastal mountains and Andes mountains that run through Chile.

Demineralisation – A chemical process to reduce the mineral content of substances, which in the case of bone leaves only collagen.

Element – A substance that is made entirely from one type of atom. Each element is distinguished by its atomic number (i.e., the number of protons in the nuclei of its atoms).

Heterogeneity – Of a different kind.

Holocene – A geological epoch, which began at the end of the Pleistocene, approximately 10,000 years ago, and continues to the present day.

Homogeneity – Of the same kind.

Horticulture – The science of growing plants, including cultivation, conservation, restoration and management.

Hunter-gatherers – Humans living in a society in which most or all food is obtained by foraging (plant collecting) and hunting of wild animals.

Hunter-gatherer-fishers – As above, but with a higher amount of fishing and mollusc gathering.

Inter-Site – Between sites. A comparison between the Fénix Archaeological Complex and other nearby sites.

Intra-Site – Within the site. A comparison of the values within the Fénix Archaeological Complex.

Isotope – Two or more forms of the same element that contain equal numbers of protons but different numbers of neutrons in their nuclei. Isotopes are more or less chemically identical, but each have a different atomic mass.

Laguna – The Spanish word for Lagoon. Used when referring to the names of the two lagoons in Quintero Bay.

Post-Burial Diagenesis – The sum of the physical, chemical and biological changes that change the composition of biogenic carbonates in the post-mortem depositional environment.

Río – The Spanish word for river. Used frequently in the maps to refer to rivers that run through Chile.

Sedentary – A term generally used to describe a lifestyle with limited mobility. This characterisation is often used for Neolithic peoples with social formations based on farming and the development of architecturally structured settlements.

Subsistence – The action of maintaining or supporting oneself, especially at a minimal level.

Tawantinsuyu – Meaning "the state of four corners". Referring to the Inka empire, which was divided into four sections: Chinchaysuyu, Antisuyu, Collasuyu and Cuntisuyu.

CHAPTER ONE: INTRODUCTION

Brief Project Background

Human skeletal material recovered from the Fénix Archaeological Complex was analysed and recorded as the Fénix Osteological Collection by Chilean physical anthropologist Margarita Rebolledo (see Rebolledo 2011a, 2011b, 2011c, 2012a and 2012b). The skeletal material in this study consists of 73 human bone samples, including phalange, rib and other small available bones. The material was obtained from four mid-late Holocene sites within the Fénix Archaeological Complex, located in the Quintero Bay area; the sites of Fénix 2, Fénix 3, Fénix 8 and Fénix 12 (32°S, 71°W) (Figure 1.1). These archaeological sites are situated in an important settlement area of mixed environments, associated with marine terrace systems and relict lakes, which created combined access to permanent marine, coastal, fresh water lagoon and forest resource systems (Galarce and Santander 2011:8).



Figure 1.1 Map of central Chile showing the location of the Quintero Bay study area.

The skeletal material examined spans a period of over 5000 years (c. 5500–550 BP), sitting between the middle Archaic Period (c. 8000–6000 BP) and the Late Intermediate Period (c. 1000–550 BP), as defined by past archaeological research for this region (see Falabella et al. 2007; Galarce and Santander 2011:44; Sanhueza and Falabella 2010). Skeletal material was selected for this research, as bone allows for an estimation of diet and landscape use in the last decades of an individual's life (Ambrose and DeNiro 1986; Katzenberg 2000; Pate 1994, 2008; Sealy et al. 1995).

Furthermore, the Fénix Osteological Collection has been the subject of detailed bioarchaeological research, including, but not limited to, full bioanthropological analysis (incorporating parasitological analysis), dental calculus studies and aDNA analysis, thus providing a wealth of contextual information pertinent to this project and a sound basis of which to deepen our understanding of the past lives of the individuals being studied (see Rebolledo 2011a, 2011b, 2011c, 2012a).

The skeletal samples analysed in this study provided the unique opportunity to learn more about the diet and landscape use of mid-late Holocene central Chilean populations. This project provides results from the largest single site isotopic analysis in Chile to date, with the triple isotope analysis (carbon, nitrogen and oxygen) of 73 human skeletal samples. While there have been other large sample sets examined from Chile, they are usually focused on multiple sites, rather than one site (see Cornejo and Sanhueza 2003; Falabella et al. 2007; Petruzzelli et al. 2012; Planella et al. 2006; Roberts et al. 2013; Knudson et al. 2009, 2012b; Sanhueza and Falabella 2010; Tykot et al. 2009). The previous focus on smaller site sample sets has been for multiple reasons, involving available material, costs, time restraints and preservation issues (see Barberena et al. 2009; Petruzzelli et al. 2012; Roberts et al. 2013; Tykot et al. 2009).

While also adhering to previous recommendations that isotopic analysis be performed on larger sample sets in Chile (see Sanhueza and Falabella 2010; Tykot et al. 2009), this study provides further insight into the subsistence methods of populations living in resource rich coastal environments. Furthermore, this research adds to the baseline data in central Chile, in a way which has previously been difficult due to the above-mentioned limitations on funding and sample sizing. Thus, this study is both important and interesting as it brings a new piece of data to the table, allowing a larger analysis of skeletal samples in central Chile and providing a baseline for future research in the region.

Skeletal Sampling Ethics

Permits and ethics for the human skeletal samples in this project were approved by the Chilean National Council for Cultural Heritage (*Consejo de Monumentos Nacionales*) (Appendix A). Furthermore, this project demonstrates considerable respect for the assemblage, with very select and small sample amounts removed from the collection after replacement casts were made of each bone sample removed. Moreover, this work fulfils the recommendations from the bioanthropological report for Fénix 3, which states the need for isotopic research to be conducted on skeletal material from the site in order to allow a better understanding of the past lifeways of the population (see Rebolledo 2012a:81). Flinders University did not require any further institutional approvals (Appendix A).

Isotopic and Elemental Analyses: A Brief Introduction

Isotopic and elemental analyses of human bone, tissue, hair and teeth have been used to examine a diverse range of characteristics related to palaeodiets and the palaeomobility of prehistoric populations (see Ambrose 1991, 1993; DeNiro and Epstein 1978, 1981; Katzenberg and Harrison 1997; Longinelli 1984; Luz et al. 1984; Schoeninger and Moore 1992; Vogel and van der Merwe 1977; Walker and DeNiro 1986). Through stable carbon, nitrogen and oxygen isotope analyses, theories about marine versus terrestrial resource use (see DeNiro and Epstein 1978, 1981; Falabella et al. 2007; Schoeninger et al. 1983; Schoeninger and DeNiro 1984; Sealy and van der Merwe 1986; 1988; Tauber 1981; Vogel and van der Merwe 1977; Walker and DeNiro 1986; Yesner 1988), the adoption of agricultural practices (see Falabella et al. 2007; Falabella et al. 2008; Hedges and Reynard 2007; Koch 1997), and human mobility (see Budd et al. 2004; Ehleringer et al. 2008; Levinson et al. 1987; Longinelli 1984; Luz et al. 1984; Moser et al. 1972; White et al. 1998) have all been successfully explored.

Furthermore, problems with interpretation, due to post-mortem diagenetic alteration of burial materials, have been investigated through both isotopic and trace elemental analyses. Trace elemental analysis has been successfully used to differentiate between different trophic levels and also between marine and terrestrial environmental signals (see Burton and Price 1990; Castro et al. 2010; Pate 1994; Pate et al. 1989; Peek and Clementz 2012; Reynard and Balter 2014). Additionally, trace elemental analysis, of elements such as uranium, has aided in the identification of post-burial diagenesis, enabling a clearer and more reliable picture of past lifeways, climate and ecology (see Collins et al. 2002; Hedges 2002; Henderson et al. 1983; Nelson et al. 1986; Pate and Hutton 1988; Pate et al. 1989; Price et al. 1992).

Stable carbon and nitrogen isotope analysis has become a commonly utilised scientific technique over the last four decades, complementing traditional archaeological methods (see Falabella et al. 2007; Katzenberg 2000; Pate 1994, 1997, 2008; Planella et al. 2014; Schoeninger and Moore 1992; Turner et al. 2009; Tykot et al. 2009). The analysis of stable carbon and nitrogen isotopes in biological materials, such as bone collagen/apatite and tooth enamel, can be employed to infer the diet of past human populations, by comparing their isotopic values with baseline values from plants and animals in the surrounding environment. Isotopic methods can therefore aid in answering questions about the introduction of agricultural foods, though a comparison of C₃ versus C₄ plant photosynthetic signals (Buikstra 1992; Buikstra and Milner 1991; van der Merwe 1982; van der Merwe and Vogel 1978; Vogel and van der Merwe 1977), and with the addition of nitrogen isotopes, marine versus terrestrial resource consumption (Ambrose 1993; Borrero and Barberena 2006; Falabella et al. 2007; Falabella et al. 2008; Hastorf 1985; Pate and Owen 2014; Sanhueza and Falabella 2010; Schoeninger and DeNiro 1984; Walker and DeNiro 1986).

Interpretations arising from analytical chemistry, such as stable isotope analyses, provide quantitative estimates of proportions of dietary components, which can be difficult to obtain via traditional archaeological analyses due to the differential preservation of floral and faunal remains, and site formation processes associated with the disposal of food debris (see Ambrose 1993; Aufderheide and Santoro 1999; DeNiro and Epstein 1978; Little and Schoeninger 1995; Petruzzelli et al. 2012; Schiffer 1987; Schoeninger and Moore 1992). In most global ecosystems, marine foods will produce a carbon isotopic signature similar to that of C_4 terrestrial plants (such as maize) (see Ambrose 1993; Falabella et al. 2008). Therefore, carbon isotope studies are often complemented by nitrogen isotope studies because nitrogen signals can be compared /contrasted with that of carbon, giving a clearer picture.

An examination of hunter-gatherer diets and landscape use, through stable carbon, nitrogen and oxygen isotope analyses, in coastal central Chile, have allowed for the formation of hypotheses regarding prehistoric human behaviour in coastal habitats with abundant and diverse food sources (see Borrero and Barberena 2006). One aspect of this is an examination of the relative contribution of various food types in hunter-gatherer versus agricultural diets. This research uses isotopic data to improve our understanding of why some central Chilean populations utilised marine resources, while others preferred different diets (see Sanhueza and Falabella 2010). The socio-cultural and environmental aspects that may have influenced these changes and continuities are considered in relation to the isotopic and elemental data from the Fénix Archaeological Complex (see Borrero and Barberena 2006; Cornejo and Sanhueza 2003; Falabella et al. 2008; Planella and Tagle 2004; Planella et al. 2005; Planella et al. 2011; Sanhueza and Falabella 2010).

Furthermore, human movement across the landscape can be examined through an analysis of oxygen isotope values in human bone carbonate deposited by ingested water (local drinking water and water contained in foods). These quantities can then be compared with oxygen isotope values in contemporary/baseline groundwater from different areas within a region, providing an estimate of mobility (see Longinelli 1984; Pate 2008; Toyne et al. 2014; Turner et al. 2009). Variation in oxygen isotopes in bone across a population therefore demonstrates a variation in access to water sources and consequently environmental and geographical conditions (Dansgaard 1964), allowing an estimation of individual mobility (Longinelli 1984).

Central Chile is well suited for oxygen isotope studies, as it is a narrow strip (approximately 200km) of country that runs between the Pacific Ocean and the Andes mountain range (Sanhueza and Falabella 2010:132). Due to variations in temperature and altitude between the east and the west of the country, there is significant differentiation in baseline water oxygen isotope values, enabling a distinction between coastal, valley and highland populations (see Sanhueza and Falabella 2010). As a result, population movements may be visible in the oxygen isotope ratios of the inhabitants from this site (see Dansgaard 1964; Falabella et al. 2007; Font et al. 2015; Knudson et al. 2012b; Longinelli 1984; Luz et al. 1984; Pate 2008; Toyne et al. 2014).

Additionally, oxygen isotope analyses can contribute to an improved understanding of carbon and nitrogen isotope values, through a crossexamination of outlying isotopic values. For example, if one person out of an entire population (an outlier) is found to have differing nitrogen values, then oxygen isotope values may be compared, indicating whether the outlier is an individual from another site (see Gil et al. 2011; Knudson et al. 2009; Toyne et al. 2014; Turner et al. 2009; White et al. 1998).

Stable isotopic analysis of these three elements together can thus form a working interpretation of the lifeways of the population, by each providing information on different aspects of human life at the Fénix Archaeological Complex.
Research Questions and Aims

This research seeks to contribute to an understanding of mid-late Holocene resource and landscape use in central Chile through isotopic and elemental analyses of human bone collagen and apatite, via the use of the Fénix Archaeological Complex as a case study. The case study data are then used to address both global and regional theories concerning diet and landscape use in the mid-late Holocene.

One of the theories that this research explores is the idea that coastal huntergatherers were heavy consumers of marine resources. According to optimal foraging theory, prehistoric populations would exploit the foods with the highest caloric return for the lowest amount of energy (Sheehan 2006:168; Smith and Winterhalder 1992; Winterhalder and Smith 1981). Based on this principle, it is expected that coastal populations would be utilising marine resources (such as sea mammals, fish, and shellfish) to at least some extent due to their proximity to the resource. Similarly, the broad spectrum revolution model is based on the idea that hunter-gatherers started consuming a wider range of foods during the Holocene, which eventually led to agricultural practices in some regions (see Flannery 1968; Hassan 1981; Zeder 2012). If hunter-gatherers were exploiting a range of foods in their environment, then it is logical to expect that coastal populations were also exploiting coastal resources.

Archaeological evidence for coastal sites around the world has indicated the importance of marine resources to prehistoric populations (see Borrero and Barberena et al. 2009; Carter 2017; Collier and Hobson 1987; Erlandson 2001; Roberts et al. 2013). However, there is also evidence for some coastal populations, with access to rich marine resources, consuming predominantly terrestrial and lacustrine resources (see Jones 1978; Nicholson and Cane 1991; Sanhueza and Falabella 2010). The mechanisms behind this differential resource use so far remain unexplained, with questions remaining as to why people with access to rich marine resources to ignore them in favour of terrestrial and lacustrine resources. However, as Carter (2017:94) has recently pointed out 'a

maritime economy is based on more than its diet but is a measured response to environmental conditions which result in cultural adaptation'. Using this idea, it is possible that some coastal populations didn't have the need to adapt to marine resource use and therefore, preferred to hunt and gather in plentiful terrestrial and lacustrine environments. This issue is further explored in this thesis with reference to the isotopic and trace elemental analyses of the skeletal material from the Fénix Archaeological Complex, adding new data to the regional and global picture.

Another subject explored in this thesis is the introduction of agricultural practices in central Chile to hunting and gathering societies, which largely took place during the Holocene around the world (see Binford 1968; Flannery 1973; Cohen 1977; Fagan 1987; Smith 1989, 2006; Weiss et al. 2004). There is evidence for the introduction of cultigens to central Chilean populations, in the form of quinoa (*Chenopodium quinoa*) horticulture during the late Archaic Period (c. 3000 BP) (see Planella et al. 2005). This was then followed by an increase in food production during the Early Ceramic Period (c. 2200–1000 BP), with the introduction of maize (*Zea mays*) agriculture (see Falabella et al. 2007; Falabella et al. 2008; Sanhueza and Falabella 2010).

One of the main questions concerning agriculture in archaeology is: Why would hunter-gatherers with access to rich resources adopt labour-intensive agricultural practices? (see Bird et al. 1985; Dillehay et al. 2012a; Falabella et al. 2007; Smith 2011). This question reflects the same research theme as the previous question, which asks why coastal populations with rich marine resources would be predominantly consuming terrestrial and lacustrine resources. Both of these questions can be explored further through stable carbon, nitrogen and oxygen isotope analyses of the population at the Fénix Archaeological Complex.

Finally, this research explores the degree of mobility of hunter-gatherers in central Chile. The term hunter-gatherer has previously been applied to highly mobile populations of people who hunt and gather food and resources from the landscape (see Binford 1968; Flannery 1969; Fagan 1987). However, it is now

acknowledged that not all hunter-gatherers have highly mobile patterns, with some preferring to stay in one location for most, if not all, of the year (see Arriaza et al. 2008; Lee 1979; Lee and Devore 1968; Price and Brown 1985; Santoro et al. 2005; Standen et al. 2018). Using oxygen isotope analysis, this issue is explored at the Fénix Archaeological Complex, contributing to a regional representation of mobility during the Holocene in central Chile.

In order to address the above theoretical debates, a broad examination of diet and mobility was conducted in this thesis through a consideration of the following primary research question:

What do stable carbon, nitrogen and oxygen isotope analyses of human skeletal material allow us to infer about changes and/or continuities in the diet and mobility of the populations at the Fénix Archaeological Complex (c. 7000–550 BP) in coastal central Chile, during the mid-late Holocene?

Following from this question, the research had two principle aims. The first was to investigate changes in diet and landscape use recorded in the chemical composition of skeletal material via isotope and elemental analyses, to achieve a more complete picture of prehistoric populations in central Chile (see Falabella et al. 2007; Hückstädt et al. 2007; Planella et al. 2014; Sanhueza et al. 2007; Schoeninger and DeNiro 1984; Schwarcz et al. 1985; Tieszen and Fagre 1993; Vogel and Van der Merwe 1977).

The second aim was to use the isotopic and elemental results from the investigation to contribute to currently held theories, both global and regional, concerning marine versus terrestrial resource use, the adoption of agricultural practices and human mobility across landscapes, by allowing a comparison of chemical and archaeological data in central Chile and beyond (see Knudson et al. 2009, 2012b; Petruzzelli et al. 2012; Roberts et al. 2013).

In addition to the primary research question, a series of subsidiary questions were explored throughout this thesis to address the primary research problem more fully. These questions are as follows:

- What do stable carbon and nitrogen isotope analyses tell us about the consumption of marine foods by the populations at the Fénix Archaeological Complex?
- What do stable carbon and nitrogen dietary values from the population at the Fénix Archaeological Complex tell us about the adoption of agriculture?
- Do the carbon, nitrogen and oxygen isotopic results reflect food and water sources from outside the local coastal area, and if so, what does this say about the movements of individuals within the internal population at the Fénix Archaeological Complex?
- Are there variances in the consumption of different food types between the ages and sexes of the individuals within the population, and could this be due to a difference in status within the population?
- Does oxygen isotope analysis of the population at Fénix Archaeological Complex reflect a highly mobile population?
- Were some individuals within the population more mobile than others (i.e., are foreigners represented within the burial population)?
- What issues impinge upon isotopic interpretation in this region?
- Does the trace element analysis identify dietary trends?
- How does the use of LA-ICP-MS address problems with post-burial diagenesis within the sample set and what does this mean for the data collected?

These research questions aim to facilitate an in-depth examination of the populations at this site, as well as contextualising other archaeological data from the Fénix Archaeological Complex.

A final and supplementary aim of this research was to improve the chronological resolution of the Fénix Archaeological Complex, through the radiocarbon dating of six human skeletal samples from four areas within the site containing skeletal material. The skeletal samples chosen for radiocarbon dating were from different areas of the complex and were the most representative materials that would allow for comprehensive refinements of the assemblage.

Significance

An assessment of significance for this project has been separated into five categories, ranging from international significance through to site-specific significance and the contributions to scientific and social-cultural studies. These multiple levels of importance provide the necessary justification for this research.

1. International Significance

The primary significance of this research is its contribution to an improved understanding of global prehistoric human resource and landscape use associated with resource-rich coastal areas. The geological, climatological and ecological variability across the landscape make the Fénix Archaeological Complex an ideal location for differentiating isotopic values. Further, stable isotope analyses of coastal sites in central Chile will allow improved quantitative analyses of the diets of the populations, which is not possible through archaeology alone, due to the differential preservation of the floral and faunal remains and site formation complexities (Ambrose 1993:59). Consequently, gaps in the research may be addressed and questions concerning human resource use and population movement can be answered. Accordingly, this research project also aimed to contribute to the international literature in this field, as well as providing more isotopic baseline data for other studies in central Chile.

2. Significance to South American Studies

This research project is significant to South American studies as it contributes data that can be cross-referenced at a continental scale. Stable carbon, nitrogen and oxygen isotope analyses can contribute to information about the relationship between the consumption of marine resources from the coast and inland terrestrial resources. This will add to our understanding of behaviours and social complexity in environments providing access to diverse food sources in greater Chile (see Barberena et al. 2009; Falabella et al. 2007; Petruzzelli et al. 2012; Roberts et al. 2013; Sanhueza et al. 2007).

This research is also significant to central Chilean studies, as it fulfils the repeated recommendation that stable isotopic studies be conducted on a large population sample, rather than smaller population groups, thereby allowing a more comprehensive picture of the population's diet and landscape use over time (see Rebolledo 2012:81; Sanhueza and Falabella 2010).

3. Site Specific Significance

This study adds value to the Fénix Osteological Collection, which was obtained through a contract archaeology project conducted by Archeos Chile, led by archaeologist Patricio Galarce. The stable carbon, nitrogen and oxygen isotope analyses undertaken in this research have added new information to the bioarchaeological and parasitological studies that have already been performed on the collection, allowing more detailed considerations of diet and mobility. Isotope analyses offer an independent quantitative line of evidence, providing a more complete picture of the behaviour of the people who were buried at the complex.

4. Scientific Significance

The scientific significance of this project is that it evaluates the strengths and/or weaknesses of combining multiple isotopic and elemental analyses in archaeological research (see Ambrose 1991; Hedges et al. 1995; López-Costas et al. 2016; Maurer et al. 2014; Nielsen-Marsh et al. 2007; Nielsen-Marsh and Hedges 2000; Owen 2003; Pate and Brown 1985; Pate and Hutton 1988; Pate et al. 1989; Pate et al. 1991; Pate and Owen 2014; Price et al. 1992; Petruzzelli et al. 2012; Roberts et al. 2013). In doing so, the research assesses the independent contribution that isotopic and elemental studies can generate in comparison with conventional archaeological evidence (see Barberena et al. 2009; Petruzzelli et al. 2012; Roberts et al. 2009; Tykot et al. 2009). Additional radiocarbon dating of the

site via the skeletal remains also serves to compare with the relative dating conducted at the site through ceramic typologies, thereby further clarifying the chronological resolution of the Fénix Archaeological Complex.

5. Social and Other Significance

Finally, this project is significant as it encompasses international collaboration between Australian and South American researchers and enhances the cooperative relationship between researchers and institutions with different expertise, working together to contribute knowledge and understanding to questions about diet and landscape use in Chile. Working mutually, with international and interdisciplinary researchers, will aid in obtaining a better picture of the lifeways of these ancient people that lived within what is currently known as Chilean territory. Furthermore, results of this research will be communicated to the local Chilean and wider scientific communities to further enhance the protection of heritage in this region.

Chapter Outline

Chapter One: Introduction

Chapter one of this thesis introduces the study, frames the research questions, summarises the significance of the study and introduces the study area and sampling and analytical procedures.

Chapter Two: Literature Review

Chapter two evaluates relevant literature and explores key theories relating to human diet and landscape use throughout the Holocene. Part one of the literature review examines the archaeological evidence of human diet and landscape use on both global and regional levels. Part two of the literature review examines the chemical evidence of diet and mobility, with particular reference to stable carbon, nitrogen and oxygen isotope analyses.

Chapter Three: Background

Chapter three reviews the climate, environment, resource and landscape use of the central Chilean region, with reference to the archaeology and skeletal collection at the Fénix Archaeological Complex.

Chapter Four: Materials and Methods

Chapter four presents and discusses the materials and methods used in this study.

Chapter Five: Results

Chapter five reviews the results of the research undertaken.

Chapter Six: Discussion

Chapter six discusses the isotopic and elemental results of the research, with reference to the archaeology of the area and the relevant global and regional literature.

Chapter Seven: Conclusions

Chapter seven presents the conclusions of this research, highlighting key points, contextualising the results and outlining recommendations for future research.

Overview

This literature review explores key theories relating to human diet and landscape use throughout the Holocene (c. 12,000 BP to present) beginning with an examination of archaeological evidence of human diet and landscape use (Part One) and progressing to a consideration of the chemical evidence (Part Two). This chapter addresses issues relating to food procurement strategies including, but not limited to, foraging, hunting and gathering, fishing and the adoption of agricultural/horticultural practices. Following this, an exploration of these themes in relation to human diet and landscape use are considered at global and regional levels, via a critical review of the archaeological and chemical evidence.

PART ONE: An Archaeological Review of Human Diet and Resource Use

Diet and Resource Use: An Introduction

Over the course of human prehistory, diet and resource use has seen some of the most significant changes during the Holocene (c. 12,000 BP to present). The Holocene epoch has witnessed varied kinds of hunting and gathering, fishing, animal domestication, incipient horticulture and the introduction to agricultural practices. Utilisation of faunal and floral resources allowed humans to expand their diets beyond anything seen previously (see Flannery 1968, 1969). This sub-chapter outlines the various mechanisms employed by human populations to obtain, use and store food resources throughout the Holocene. Starting with hunting and gathering, and finishing with the introduction of agricultural practices, this study, however, recognises that the processes involved do not represent a linear "progression", but rather adaptive strategies used by a range of prehistoric populations associated with different environmental and cultural contexts.

Terrestrial and Marine Resource Use

Hunting and Gathering

Hunter-gatherers were/are highly mobile bands of people who survive by hunting wild animals and gathering plant foods (see Binford 1968; Flannery 1969; Fagan 1987). Prehistoric peoples' main form of subsistence was hunting and gathering (Binford 1968; Flannery 1969; Fagan 1987; Price and Bar-Yosef 2011). This entailed the hunting of small and large animals, fishing, and gathering, or foraging for plant foods. Hunting and gathering remained the primary subsistence technique for 90% of humans' time on earth (see Binford 1968; Flannery 1969; Fagan 1987; Price and Bar-Yosef 2011; Smith and Winterhalder 1992). Some examples of populations that survived by hunting and gathering practices are the Clovis big game hunters of the Americas, who were highly mobile bands of hunter-gatherers during the late Pleistocene (see Raff and Bolnick 2014; Rasmussen et al. 2014; Waters et al. 2007), the Aboriginal peoples of Australia, who exhibited mobile hunting and gathering strategies in marginal habitats (see Borrero 2011; Gould 1980, 1984, 1991; Hiscock 2008; Jones 1979; Roberts et al. 1990; Tonkinson 1978; Yengoyan 1976), the coastal hunter-gatherers of California and northwest North America who did not choose to participate in agricultural practices (see Lee and DeVore 1968), and the !Kung San people of northern Botswana who moved between hunting and gathering and agricultural practices during times of stress (see Lee 1979). Theories about hunting and gathering seek to explain why and how human populations obtained food in order to survive in a range of environmental contexts.

Optimal Foraging Theory

One of the main theories to take root in archaeological hypotheses was optimal foraging theory (Price and Bar-Yosef 2011:S167; Smith and Winterhalder 1992; Winterhalder and Smith 1981). Optimal foraging theory is a model for predicting foraging behaviour and is borrowed from ideas from evolutionary ecology (see Charnov 1976; Emlen 1966; MacArthur and Pianka 1966). It seeks to explain the mobility, resource use and dietary patterns of past humans (Price and Bar-Yosef 2011:S167). Optimal foraging theory is based on the idea that hunter-gatherers would likely employ the most energy efficient foraging strategies by selecting foods with the highest amount of caloric return for the lowest amount of energy output (Sheehan 2006:168). Optimal foraging theory suggests that low caloric or high cost foods are only employed when there is a resource depression. Thus, optimal foraging theory assumes that humans make deliberate and rational decisions based on economic efficiency (see Mithen 1988; Smith 1983:626). However, this theory cannot adequately explain the role of culture in making human dietary decisions (Price and Bar-Yosef 2011:S167). The adoption of cultivation and agricultural practices may have originally been an additional way for hunter-gatherers to control the amount of time they spent searching for food. In addition, risk-minimisation would have likely played a major role in the structure of hunter-gatherer food management systems in relation to seasonality and scheduling of food resources (see Flannery 1968).

Broad Spectrum Revolution (BSR)

Another archaeological theory relating to the investigation of subsistence practices, is the broad spectrum revolution (BSR) concept. The broad spectrum revolution was first proposed by Flannery (1969) to explain a broadening of the subsistence base outwards to encompass a greater selection of food sources. Originally, Flannery (1969) linked

resource diversification and intensification to imbalances between population density and environmental carrying capacity.

The influence of population pressure and environmental change is in accordance with the optimal foraging theory framework, where diversification and intensification of resources only occurs within the context of resource depletion, caused by population pressure or environmental factors (see Flannery 1969; Zeder 2012). Once a population has exceeded its environmental carrying capacity, BSR (with an OFT framework) suggests that instead of hunter-gatherers exploiting only high-value (low cost to benefit ratio) prey, low-value (high cost to benefit ratio) prey would be included in greater quantities in the cases where there was insufficient high value food to support the population (Flannery 1969). An example of this is, instead of people only hunting large, slow animals and easy to harvest plants, during times of greater need they would start broadening their spectrum to include difficult to extract plants and small, fast animals or fish to survive (Flannery 1969). However, the idea that populations were forced to adapt to declining availability of optimal resources through the BSR is questionable, due to numerous examples of diversity and intensification being documented in contexts of resource abundance (see Zeder 2012). Additionally, Flannery (1986) adjusted his original BSR concept, noting that population pressure was unlikely to be a primary cause of the broadening of resource use and the subsequent introduction to agricultural practices (see Hassan 1981). Flannery (1986:14) suggested that the BSR was instead a tool to enhance the predictability of resources throughout the environment, leading to agricultural practices and intensification of resource uses.

Intensification

'Intensification refers to the process by which human groups obtain more resources in a given unit of time or space in relation to an earlier period' (Boserup 1965:44).

Economist, Esther Boserup (1965) proposed an early model of intensification that was comprehensive, yet simplified what was to become a complex theory of intensive practices. Boserup's (1965) theory was centred around the idea that population pressure caused a decrease in available resources and was thus the driving force behind intensification. This theory rested on the idea that a decline in the foraging efficiency of

the population caused the shift to more intensive practices. This theory is consistent with the earlier mentioned optimal foraging theory (see Broughton 1997; Butler 2000; Sheehan 2006; Smith and Winterhalder 1992; Winterhalder and Smith 1981), because it suggests that humans increased the use of lower-ranked resources as the population density grew and resource depression caused the higher ranked resources to become unavailable (see Alexander et al. 1986).

Alternatively, it was originally thought that an increase in foraging efficiency (related to increased labour when procuring and storing food), led to economic changes and social complexity within populations (see Ames 1985; Fitzhugh 2003; Hayden 1992). Intensification has been seen as underwriting social and political complexity through the reconstructing of human labour for the differentiation of non-food production and the support of non-producers (Lourandos 1985, 1988, 1993; Zangrando 2009:593).

Zangrando's (2009) multi-level model illustrates the variables of the intensification process (Figure 2.1). This model shows that stress, in the form of environmental change and population growth, leading to resource depletion, leads to a decrease in foraging efficiency, which leads to intensification and thus more labour investment. Labour investment then involves increased effort leading to specialisation and diversification.

Specialisation, or focussing on a narrower range of species, leads to an increase in the efficiency of previous effort. Logistical organisation and technological production are prioritised in order to more efficiently procure specialised resources. Efficient procurement of specialised resources can also lead to increased storage of resources while they are concentrated. A concentration of resources in one area may also lead to increased competition for that area, creating social hierarchies to manage resources (see Grayson et al. 2001; Kelly 1995; Zangrando 2009).



Figure 2.1 Flow chart showing the process of intensification. Chart adapted from Zangrando (2009).

On the other hand, diversification, or increased effort focussing on a broader range of species, can lead to the development of new technologies and techniques used in addition to existing strategies. Diversification is based on the exploitation of resources spatially and temporally across the landscape and allows for more flexible social relations in order to respond to changing economic requirements (see Binford 2001; Earle 1980; Morrison 1994). Diversification can also lead to changes in social roles, such as the formation of social hierarchies through differential labour organisation (e.g., women and children participating in increased foraging activities) (see Lupo and Schmitt 2005; Zangrando 2009). Overall, both specialisation and diversification can lead to socio-economic complexity in hunter-gatherer societies (Hayden 1992; McRostie et al. 2017; Price and Burton 1985; Zangrando 2009:593).

Hunter-Gatherer-Fishers

Hunter-gatherer-fishers, or marine hunter-gatherers, have been defined as 'those for whom marine foods form the largest portion of the intake of either calories or protein in the diet' (Yesner 1980:728). It was first believed that prior to 5800 BP, marine resources were only occasionally utilised to supplement a terrestrial diet obtained from hunting and gathering (Lanning 1967). However, archaeological evidence has been found for the exploitation of marine resources as early as 164,000 years ago, at the site of Pinnacle Point in South Africa (see Marean et al. 2007:905). In addition to this, there is faunal evidence for the exploitation of near shore marine resources on the Red Sea coast of Eritrea in East Africa, by 125,000 years ago (see Walter et al. 2000). Furthermore, archaeological evidence, in the form of shellfish remains, indicated that settlements associated with marine resources were found throughout Africa, Asia, Europe, Australia and the Americas during the Pleistocene (Erlandson 2001:309).

One of the problems with early marine sites is their visibility, or lack thereof, in the archaeological record. Postglacial sea-level rise and other environmental variables (such as erosion) have contributed to an under-representation of coastal adaptations in archaeology (see Kraft et al. 1983; Lee-Thorp et al. 1989; Parkington 1981; Sandweiss 2008; Sealy and van der Merwe 1988). This is because coastlines move laterally in response to sea-level changes, meaning that some modern coastal sites were previously

inland, and many early coastal sites are likely submerged (see Erlandson 2001; Parkington 1981).

According to Erlandson (2001:301), the maximum lateral movements of coastlines in the past 20,000 years have varied from between 1000 km in some areas to less than 1 km in other areas. Additionally, sea levels were between 125 m and 100 m lower than they are today, which created broad coastal plains around the world that would have been inundated as sea levels rose (Erlandson 2001:301). Thus, areas around the world where sea levels were the most stable usually tend to be the ones where early archaeological coastal occupations are found (Erlandson 2001:302).

Coastal Resource Use during the Holocene

During the Holocene, marine resource use generally increased globally (see Carter 2017; Erlandson 2001; Hiscock 2008; Sandweiss 2008). One reason for this could be that the warming trend at the end of the Pleistocene led to new and generally richer coastal environments, which may have aided in the use and exploitation of marine resources (see Straus et al. 1996). Human adaptation to, and the development of, a marine-based economy involved gaining knowledge about available resources, feeding/foraging habits of each animal, seasonality of foods, the influence of tide and weather, the skills required to acquire resources, and risk management associated with food procurement (e.g., fishing, diving etc.) (Carter 2017:105). Using this knowledge, coastal populations may have adapted to coastal living and began exploiting marine resources. Some examples of archaeological coastal populations/locations of marine subsistence around the world are: the Jomon culture of Japan (see Habu et al. 2011), the Ertebølle culture of Scandinavia (see Miller et al. 2010), the Whitsunday Islands in Australia (see Barker 2004), Daisy Cave in California (see Erlandson et al. 1996), the Ring Mounds in south eastern North America (Thompson and Worth 2010) and Huaca Prieta on the central coast of Peru (see Dillehay et al. 2012b).

Conversely, not all coastal populations exploited marine resources throughout time, with some populations, such as those living on the coast of Anxious Bay in Australia (see Nicholson and Cane 1991) showing limited evidence for marine resource use despite the proximity to the coast, and other coastal populations showing little to no evidence of marine resource utilisation during particular times in prehistory (see Hiscock 2008; Jones 1971). One example of this is on the island of Tasmania, located at the south-east tip of Australia. Jones (1971) excavated two caves, Rocky Cape North and Rocky Cape South, on the northern coastline of Tasmania (Figure 2.2). Archaeological evidence found in the caves consisted of lithics, charcoal layers (from hearths), and faunal remains (including seals, fish, shellfish, wallabies, bandicoots, wombats, possums and bird bones) (see Jones 1971:525–530).



Figure 2.2 Location of Rocky Cape sites in Tasmania, Australia. Map adapted from Google Maps and Jones (1971).

Archaeological deposits from the Rocky Cape caves stretched from more than 8000 years ago until historic times (c. 6000–435 BP) (Jones 1971:198). During the excavations, hundreds of fish bones were identified in the lower stratigraphic layers of the deposits (Jones 1971:526). However, evidence of fish bones was not present in the stratigraphic layers dated to after c. 3700 BP, where it appears that fishing at the sites altogether disappeared (Jones 1971:540). Along with the disappearance of fishing, were also changes in technology, such as the cessation of bone tool manufacture at the same time and the increased presence of imported stone tools (from inland areas) (Jones 1971:525).

Jones (1971, 1977, 1978) believed that the abandonment of fishing was part of a fundamental restructuring of Aboriginal life in northwest Tasmania, which included cultural degeneration and economic dysfunction. Conversely, the avoidance of fish as a food source could have been related to economic and social changes within Aboriginal society that had nothing to do with "cultural degeneration". Furthermore, climatic conditions, such as the onset of El Nino conditions (from 5000–2000 BP), contributed to a drier and more variable climate, changing foraging conditions (see Gagan et al. 2003). Additionally, there is evidence for a greater exploitation of food from the lower littoral zones (such as abalone and lobster) as well as the inland areas, reflecting a diversification of landscape use and a reconfiguration of foraging practices, resulting in the reduction of coastal living (Hiscock 2008:143).

Coastal Resource Use: South America

Archaeological evidence, in the form of fish, shellfish and plant and animal remains, has demonstrated that early humans engaged in hunting, gathering and fishing along the coasts of South America from approximately 15,000 BP (see Dillehay et al. 2017). While some of the earliest sites related to marine adaptations can be found along the western coast of South America, bordering the Pacific Ocean, there are still a diverse range of hunting, gathering and fishing sites located on other coasts throughout South America.

As mentioned previously, sea-level fluctuations have had an impact on the number of coastal sites that are visible in the archaeological record (see Erlandson 2001). Some of the earliest coastal sites in South America are on the Pacific Coast (e.g., Monte Verde, Huaca Prieta), where the relatively steep bathymetry and coastal uplift have limited the lateral elimination of postglacial shorelines (Erlandson 2001:317; Richardson 1998).

As sea levels rose with deglaciation from 21,000 to 5800 cal BP, many coastal sites along the wider continental shelf were inundated, affording Lanning's (1967) view that marine resources were only occasionally utilised before 5800 cal BP. However, in places where the continental shelf was narrow, such as Quebrada Jaguay and Quebrada Tachuay in Peru, evidence of earlier coastal sites is present (Sandweiss and Richardson 2008:100).

North, East and South Coasts of South America

The north, east and south coasts of South America have provided much in the way of archaeological evidence for the exploitation of marine resources by coastal peoples. At northern South American sites, such as Taima-Taima, Rio Pedregal and Cucuruchó in Venezuela (see Oliver and Alexander 2003), La Elvira in Colombia (see Gnecco and Salgado 1989; Gnecco 1994), and sites within the Guianas Shield (see Rostain 2008), there is evidence of early marine adaptations (Figure 2.3).

Furthermore, on the eastern coast of South America, archaeological evidence in the form of *sambaquis* (shell mounds) all along the eastern and southern Brazilian coastline (see Wagner et al. 2011; Zangrando 2009), provide evidence of extensive marine resource use during the late Pleistocene and early Holocene (see Dillehay 2008:31). Sites such as Cerro la China and Cerro el Sombrero on the Argentinean coast also provide evidence of early coastal adaptations in South America (see Flegenheimer 1986, 1987). Additionally, in the far south of South America, archaeological sites in the Beagle Channel have also been found to indicate an intensive maritime subsistence strategy (see Zangrando 2009).



Figure 2.3 Map of north, east and south, South American sites mentioned in text. Map adapted from Dillehay (2008).

The Guianas Shield is an area of approximately 1,800,000 km² of northern South America, which encompasses parts of Colombia, Venezuela, Guyana, Suriname, French Guiana and Brazil (see Williams 2003) (Figure 2.4). The Guianas Shield area is bordered by the Amazon and Negro rivers, the Casiquiare Canal, the Orinoco River and the Atlantic Ocean, making it an "island" of sorts (see Rostain 2008). The Guianas Shield is made up of three main ecological zones: grassy savannahs, inland rainforests and coastal plains (Rostain 2008).



Figure 2.4 Map showing the Guianas Shield Area. Map adapted from Rostain (2008).

Around 3000 BP, shellfish gatherers settled on the Guianas coastal plain (Rostain 2008:283). To date, shellfish mounds have not been found on the coasts of Suriname, French Guiana and Brazil, as the muddy banks from Amazon river sediment prevent the development of shellfish in these areas (Versteeg 2008:303). This is contrary to the west and east of the Guianas Shield in Brazil, Guyana and Venezuela, where shell middens are numerous, proving evidence for human settlement (Rostain 2008:283). In these areas, preceramic and early ceramic shell mound sites are known as *sambaquis*, which were made by the dumping of significant amounts of shellfish remains over time. *Sambaquis* have been found along the east coast of Brazil throughout the Holocene (see Neves 2008; Suarez et al. 2010) (Figure 2.5).



Figure 2.5 Location of *sambaquis* in Brazil. Map adapted from Gaspar (2008).

The *sambaquis* of the east coast of Brazil are one example of prolific marine resource use during the Holocene in South America (Figure 2.6). According to Gaspar et al. (2008:319) there are more than one thousand *sambaqui* locations recorded in Brazil's national archaeological register. However, the actual number of *sambaquis* in Brazil is unknown due to modern settlements coinciding with locations in which the mounds would have been, due to mounds typically being built in highly productive bay and lagoon environments (Gaspar et al. 2008:319).



Figure 2.6 *Sambaquis*: Figueirinha I (foreground) and Figueirinha II (background right). Photo courtesy of Tiago Attorre.

Cultural inclusions in *sambaquis* are variable, with a range of additions, including stone, bone and shell artefacts, burned bone, clusters of burials, hearths and postholes (Gaspar et al. 2008:319). The earliest date for *sambaquis* in Brazil is 9200 BP at inland sites along the Ribeira de Iguape. Small mounds of edible land snails, with stratigraphic features resembling those of coastal locations were found along the river (see Figuti et al. 2004). Additionally, a *sambaqui* at the coastal end of the Ribeira de Iguape dates to 8000 BP, demonstrating possible evidence for coastal contact up the river (see Barreto 1998; Calippo 2004; Gaspar et al. 2008:320). However, the majority of radiocarbon determinations for Brazilian *sambaquis* are concentrated between 4000 BP and 2000 BP (Gaspar et al. 2008:320). Furthermore, by approximately 2000 BP there was a decrease in the use of shell and a switch to dark earth, with the eventual disappearance of *sambaqui* traditions during the late Holocene (Gaspar et al. 2008:328).

Extensive food remains and prominent clusters of burials characterise almost all investigated *sambaquis* throughout the central and southern coasts of Brazil (see Gaspar 1998; Wagner et al. 2011). The smaller *sambaquis* have been interpreted as likely being used as either food processing stations or campsites. However, there has so far been no evidence of recognisable dwellings, and indications of domestic activity are largely absent at Brazilian *sambaquis* (Gasper et al. 2008:319). Additionally, the large *sambaquis* have been loosely interpreted as having mortuary functions, due to their complex

stratigraphy and abundance of burials within the mounds (see Fish et al. 2000; Gaspar et al. 2008:319; Wagner et al. 2011).

Sambaquis have been strongly associated with hunting and gathering societies, whose primary dependence was on fishing and mollusk collection (Gaspar et al. 2008:321). Further, broad similarities in *sambaqui* mound construction, as well as shell, bone and lithic remains have been interpreted as evidence of social interactions between populations all along Brazil's coastline, illustrating marine exploitation by Holocene populations along the eastern coast of South America (Gaspar 1998; Gaspar et al. 2008:329).

Further south, in the Beagle Channel region on the Fuegian archipelago of southern South America, eight zooarchaeological sites within three archaeological areas were examined for evidence of hunter-gatherer fishing intensification (see Orquera and Piana 1999a, 1999b; Zangrando 2009) (Figure 2.7). The sites analysed were mid-late Holocene shell middens, dated from approximately 6400 BP up until present times (Zangrando 2009:590). Faunal remains at the sites indicated an increase in fish remains and a decrease in mammal remains during the last 1000 years in the archaeological sequence of the Beagle Channel sites.



Figure 2.7 Map of southern South America, showing the location of the Beagle Channel. Map adapted from Zangrando (2009).

Zangrando (2009:604) argues that it is not possible to suggest a population pressure model, as is implied by many intensification models, as the reason for the intensification in this region. However, it is instead suggested that a slight increase in population during the late Holocene may have caused foraging variations on a regional scale, which in turn raised fish productivity at the Beagle Channel sites (Zangrando 2009:604). Ultimately, this study shows that resource intensification is a multidimensional process where changes towards intensification are not necessarily straight paths towards social complexity (Zangrando 2009:604).

Western Coast of South America

The coast of western South America has one of the most productive marine ecosystems in the world due to upwelling associated with the nutrient rich Humboldt current (Sandweiss 2008:146) (see Background Chapter for details on this). At Peruvian late Pleistocene and early Holocene sites, such as Huaca Prieta (see Bird et al. 1985; Dillehay et al. 2012a, 2012b), Guañape (see Bird 1948), Ancón-Chillón (see Richardson 1981), Quebrada Jaguay (see Sandweiss et al. 1998), The Ring Site (see deFrance et al. 2009; Sandweiss et al. 1989), Quebrada Tacahuay (see deFrance et al. 2001; Keefer et al. 1998) and Quebrada de los Burros (see Carré et al. 2009; Lavallée et al. 2011), archaeological evidence in the form of shell mounds, faunal remains and fish hooks illustrates an early maritime economy for coastal populations (Figure 2.8). Furthermore, northern Chilean sites, such as Acha I (see Standen and Santoro 2004), Acha II (see Muñoz et al. 1993), Acha III (see Standen and Santoro 2004), La Chimba 13/Quebrada de las Conchas (see Llagostera 1977, 1979), Caleta Vitor (see Carter 2017; Santoro et al. 2017a) and Taltal (see Andrade et al. 2015), also show archaeological evidence (fish hooks, shell mounds etc.) of a predominantly marine economy.



Figure 2.8 Map showing locations of archaeological sites on the west coast mentioned in the text. Map adapted from Dillehay et al. (2008).

Investigations of coastal archaeological sites in western South America were initiated by Barrington Brown (1926), who reported the existence of preceramic sites on the coast of South America (Sandweiss 2008:146). Following this, was the work of Junius Bird in the 1930s and 1940s, closely succeeded by the work of Frédéric Engel from the 1950s up until the 1980s (see Bird 1943, 1948; Bird et al. 1985; Engel 1957, 1980).

During the 1960s, the first detailed sequence for the coastal preceramic epoch was produced by Edward Lanning (see Lanning 1963, 1967). Unfortunately, this sequence only went back as far as 5800 cal BP, due to Lanning's failure to take into account sea level change during the late Pleistocene and early Holocene (see Richardson 1981). In the same region, during the late 1960s, Michael Moseley furthered Lanning's (1967) research, by noting that animal remains at the archaeological sites were predominantly marine and hypothesised that seafoods, not just agriculture, underwrote the first formation of Andean civilisation (see Moseley 1968, 1975; Sandweiss 2008:148).

Throughout the 1970s and 1980s, James Richardson III discovered early and middle preceramic period sites on the northern coast of Peru that contained abundant evidence of marine resource use (see Richardson 1969, 1973, 1978). In the early 1980s, Richardson (1981) proposed that central Peruvian coastal dwellers during the early and middle preceramic periods likely were consuming marine resources, but that the evidence for this was scanty due to the sites being under water, due to sea-level rise.

By the end of the 1980s archaeologists had excavated numerous early-mid Holocene marine sites, dating between 9000 and 5000 years ago on the Peruvian and Chilean coasts of western South America (see Llagostera 1977, 1979; Richardson 1981; Sandweiss et al. 1989). However, at the time of the investigations, the predominantly marine influence was classified as a periphery development in the face of research into the introduction of agricultural practices (Sandweiss 2008:148).

The last few decades of research into marine adaptations in South America have seen major advances in the studies of hunter-gatherer-fisher societies (see Erlandson 2001). This is a result of the development of general theory, a focus on marine adaptations and marine resources and further archaeological studies of prehistoric subsistence and

settlement in South America (see Carter 2017; Dillehay et al. 1997, 2017; Erlandson 1994; Erlandson et al. 2007; Jackson et al. 2004; Keefer et al. 2004; Llagostera 1992; Núñez et al. 1994; Sandweiss 2008). Consequently, the study of early South American coastal sites has become more prevalent in archaeology.

One of the earliest archaeological sites on the western South American coast is the site of Quebrada Jaguay 280 (QJ-280), in southern Peru. Quebrada Jaguay was initially investigated by Frédéric Engel in 1970, who obtained the first radiocarbon dates from charcoal in one of his test pits (see Engel 1981). From 1996 to 1999 Sandweiss and colleagues (1998, 1999) surveyed the area and excavated QJ-280, determining that it was occupied between 13,000 and 8300 cal BP, based on a suite of 41 charcoal dates (see Sandweiss et al. 1998, 1999). Smaller sites located in the immediate area of QJ-280 were also radiocarbon dated, with dates ranging from the early Holocene onwards (see Sandweiss et al. 1998). Consequently, early dates for Quebrada Jaguay represent one of the first coastal settlements of the region during the Terminal Pleistocene Epoch (Sandweiss 2008:150).

The site of Quebrada Jaguay is currently located 2 km from the coast, but during the Pleistocene would have been approximately 7–8 km inland due to sea-level changes over time (see Richardson 1969, 1973; Sandweiss et al. 1998:1). The site of QJ-280 contains a shell midden deposit with remains of fish, shellfish and crustaceans (Sandweiss et al. 1998:2). Additionally, post holes at the site indicate roughly rectangular dwellings, with the remains of hearths, food refuse and lithic debitage found within (Sandweiss 2008:151). The presence of obsidian from a highland *Alca* source (165 km away), indicates possible movement or trade with Andean highland communities (see Burger et al. 1998; Sandweiss et al. 1998).

During the early phase, QJ-280 is thought to have been a domestic centre for fishermen targeting wedge clams (*Mesodesma donacium*) and drum fish (*Sciaenae* family) (see McInnes 1999; Sandweiss et al. 1998). Following this, Quebrada Jaguay was thought to be a domestic site, with a maritime economy and evidence for trade or movement between the coast and highlands. Sandweiss (2008:151) believes that the QJ-280 site was likely a seasonal coastal base camp, which included movement to the adjacent highlands.

Additionally, the population present during early phase of QJ-280 is believed to have had a well-developed and specialised marine subsistence strategy.

To the far north of the Quebrada Jaguay site, lies the large coastal mound settlement of Huaca Prieta. Huaca Prieta was occupied from the late Pleistocene (15,000 cal BP) up until the late Holocene (c. 600 cal BP), with the first phase of mound construction starting at 7572 cal BP (see Bird et al. 1985; Dillehay et al. 2012a, 2012b:68; Dillehay et al. 2017). Initially the mound at Huaca Prieta was excavated by the American archaeologist Junius Bird in the 1940s, revealing evidence of a marine based economy, with the addition of agricultural practices by the mid-late Holocene (5500–4200 cal BP) (Dillehay et al. 2012a:418). Additionally, more recent excavations along the coastal terrace have provided the earlier dates from beneath the mound level (Dillehay et al. 2017:1) (Figure 2.9).



Figure 2.9 The Huaca Prieta mound with late Pleistocene and early Holocene cultural deposits indicated by the dotted line below the terrace. Arrows show location of excavated units. Photo courtesy of Tom D. Dillehay (see Dillehay et al. 2017).

The site of Huaca Prieta includes extensive shell middens containing a wide array of both terrestrial and marine species, incorporating 19 fish species, 34 shellfish species and eight mammalian species (including sea lion, dolphin and whale) (see Dillehay et al. 2012a, Dillehay et al. 2012b). The site also contains evidence of maize remains dated to the mid-Holocene (6755–6504 cal BP), indicating the inclusion of agricultural practices at the site. However, the abundance of marine remains throughout all periods of the site support the notion that the economy was predominantly marine-based, with the addition of agricultural products (see Dillehay et al. 2012a, Dillehay et al. 2012b).

Dillehay et al. (2012b:68) state that the rich coastal environment of the site supported a mixed maritime, lacustrine and terrestrial economy that gave rise to one of the earliest developments of cultural complexity in the Americas. These developments have been attributed to both environmental circumstances (e.g., the fertile, but arid, coastal plain, with rivers from the Andes) and emerging ideologies adopted by these communities (Dillehay et al. 2012b:69). Huaca Prieta was a place where important architectural, technological and cultural innovations occurred, and to date has no antecedents (see Bird et al. 1985; Dillehay et al. 2012a, 2012b).

An example of climate, environment and social ideologies having an influence on a population's survival techniques, is at sites along the arid southern coast of Peru and northern coast of Chile, where the harsh environment and climate of the Atacama Desert restricted terrestrial and lacustrine food sources (see Carter 2017; Grosjean and Núñez 1994; Marquet et al. 2012; Roberts et al. 2013; Santoro et al. 2012). One of the populations living on the coasts of southern Peru and northern Chile was the Chinchorro group, who became highly skilled fishers and whose reliance on marine resources allowed them to endure the severe conditions of the Atacama Desert and adopt a sedentary way of life (Arriaza et al. 2008:45).

The Chinchorro cultural complex began around 9000 BP and is named after Chinchorro beach, in northern Chile, where the remains of artificially mummified humans were first found by German archaeologist Max Uhle (see Arriaza 1995a; Llagostera 2003; Standen and Santoro 2004; Uhle 1919). Chinchorro artificial mummification of their dead was a

practice that lasted for over 3500 years (c. 7000 – 3500 BP) (Arriaza 1995b:36) (Figure 2.10).



Figure 2.10 Photo of a Chinchorro Mummy from the Museo San Miguel de Azapa, Universidad de Tarapacá. Photo courtesy of Chris Carter (2017).

The Chinchorro culture has been classified as the earliest preceramic fishing society based along the coast of northern Chile and southern Peru (Arriaza 1995a:15). Sites such as Quebrada Jaguay (see Richardson 1973; Sandweiss et al. 1989), The Ring Site (see Llagostera 1992), Quebrada Tachuay (see Keefer et al. 1998; Sandweiss et al. 1998), Quebrada de los Burros (see Carré et al. 2009; Lavallée 1999), the Acha and Chinchorro sites (see Arriaza 1995a; Uhle 1919), Caleta Vitor (see Carter 2017), Quebrada de Camarones (see Schiappacasse and Niemeyer 1984), Pisagua Viejo (see Núñez et al. 1975; Rivera and Aufderheide 1995), Punta Pichalo (see Bird 1946), Tiviliche (see Núñez

and Moragas 1978), Patillos (see Llagostera 2003) and Quebrada de las Conchas (see Sandweiss et al. 1998; Wise 1999) in southern Peru and northern Chile, all contain shell middens dating back to Chinchorro times (Arriaza et al 2008:47; Salazar et al. 2015; Santoro et al. 2018) (Figure 2.11).

Archaeological evidence of the Chinchorro cultural complex includes large shell middens, containing fish, shellfish, marine mammals and wild camelids (Arriaza et al. 2008:47). Additionally, a well-developed maritime toolkit and the presence of artificially mummified human remains have helped define the Chinchorro sites based in these areas (Arriaza 1995a; Arriaza et al. 2001; Santoro et al. 2005).





The end of the Chinchorro phase was heralded by an abrupt change in funerary practices around 3500 BP, that no longer included artificial mummification (Aufderheide 2003:141). This was followed by evidence of Altiplanic or Andean cultures appearing in the coastal valleys of northern Chile by the same epoch (Aufderheide 2003:147; Rothhammer et al. 2009; Rothhammer et al. 2017). Additionally, after approximately 3000 BP, ceramics became more prevalent and simple agricultural practices were introduced, eventually leading on to more intensive cultivation and trade (see Carter 2017:79; García et al. 2014; Munoz et al. 2016; Núñez and Santoro 2011).

Another coastal northern Chilean site that shows evidence of a maritime economy is the site of Caleta Vitor, located 29 km south of the northern Chilean city of Arica (see Carter 2017; Santoro et al. 2017a) (Figure 2.12). The area of Caleta Vitor contains seven archaeological sites (labelled CV1 to CV7), with an associated date range of c. 9000–476 BP (Roberts et al. 2013:2370). However, skeletal remains from four of the sites in this area (CV1, CV2, CV3 and CV4) have been radiocarbon dated to between 4000 and 476 years BP (Roberts et al. 2013:2370).



Figure 2.12 Photo of the Caleta Vitor area, facing north-west. Author's photo.

The Caleta Vitor area consists of extensive occupation and burial sites scattered broadly along a coastal setting (see Carter 2017:141). Sub-surface archaeological material was exposed in many areas and included human remains – both skeletal and Chinchorro artificially mummified (see Carter 2017:268). Excavated materials from the Caleta Vitor sites included shell, faunal and floral remains, lithics, textiles, ceramics and wooden implements (Carter 2017:217).

Archaeological evidence at Caleta Vitor indicates that although the original inhabitants arrived from the north, they already had a well-developed economy based on marine resources (Carter 2017:448). At the end of the Chinchorro phase (c. 3500 BP), ceramics and simple textiles were introduced (Carter 2017:428). Later, agricultural practices were introduced, which supplemented the primary economy based around marine supplies (Carter 2017:434). According to Carter (2017:449), archaeological evidence at the site of Caleta Vitor indicates that while an increasing range of products became available to the inhabitants of the sites over time, they still chose to remain focussed on the sea and marine resources.

Coastal Landscape and Resource Use: Central Chile

The landscape of central Chile is vastly different to the landscape in northern Chile. Where northern Chile is bordered by the arid Atacama Desert, which receives almost no rain annually, central Chile has a Mediterranean climate, with permanent rivers and a varied environment containing fertile inland, valley and coastal areas (see Background Chapter for detailed review of central Chilean resource and landscape use).

During the Archaic Period (c. 10,000–2200 BP) in central Chile, populations were mostly highly mobile hunter-gatherers and fishers (see Falabella et al. 2007; Falabella et al. 2016; Núñez et al. 2016; Sanhueza and Falabella 2010; Uribe and Sánchez 2016). Towards the end of the Archaic Period and during the introduction of the Early Ceramic Period (c. 2200–1000 BP), some populations shifted to mixed subsistence methods such as hunting and gathering, complemented by agricultural practices. Approaching the Late Intermediate Period (c. 1000–550 BP), central Chilean populations tended towards a more sedentary lifestyle, with the utilisation of agricultural practices and animal domestication (see Falabella et al. 2007; Sanhueza and Falabella 2010). It is important to

note, however, that not all populations during these time periods moved from one subsistence practice to another, with some populations choosing to move back and forth between subsistence practices (such as hunting, gathering and fishing and agricultural/horticultural practices) as was needed (see Falabella et al. 2007; Sanhueza and Falabella 2010).

On much of the coast of central Chile, hunter-gatherers had access to rich terrestrial, marine and lacustrine resources (see Castro et al. 2016; Cornejo et al. 2014; Falabella et al. 2007; Galarce and Santander 2011; Sanhueza and Falabella 2010; Santoro et al. 2005). Archaeological evidence, in the form of faunal remains (such as shells and bones), indicates that marine species were heavily exploited by coastal populations (see Falabella et al. 1994; Falabella et al. 2008; Galarce and Santander 2011; Sanhueza and Falabella 2010). However, where coastal populations in the north of Chile were found to be transporting marine resources into the interior, central Chilean populations could support terrestrial hunting and gathering to a much better extent and therefore did not need to rely as heavily on marine resources (see Petruzzelli et al. 2012; Roberts et al. 2013; Sanhueza and Falabella 2010). Archaeological sites on the central Chilean coast demonstrate evidence of hunting, gathering and fishing practices, though there is, to date, no evidence of a maritime toolkit (Sanhueza and Falabella 2010). Sites such as Laguna El Peral-C (see Falabella and Planella 1991), Las Brisas (see Ciprés 2003), Punta Caraumilla (see Jerardino et al. 1992; Ramírez et al. 1991), Arévalo 2, Cancha de Golf 1, and El Trébol (see Falabella et al. 2007) all show archaeological evidence of the use of coastal/marine resources (Figure 2.13).



Figure 2.13 Map of central Chilean coastal sites referred to in text. Map adapted from Falabella et al. (2007); Falabella and Planella (1991); Sanhueza and Falabella (2010).

One example of a central Chilean coastal site which shows faunal evidence of marine resource use is the site of Laguna El Peral-C (LEP-C). LEP-C is an Early Ceramic coastal site dated between approximately 1550 and 1200 BP (Falabella and Planella 1991; Falabella et al. 1994:30). Archaeological evidence, in the form of faunal remains (fish bones and shells), indicates that the inhabitants of the site were utilising marine resources (see Falabella and Planella 1991). However, differential preservation and diverse excavation procedures at the site have resulted in a variation in the recovery of faunal remains (see Falabella et al. 1994). After a study conducted by Falabella et al. (1994:33) it was established that, despite the variation in recovered remains, the inhabitants of LEP-C were not systematically using the sublittoral zone. Instead, inhabitants of the site were exploiting species feeding near rocky shore or very close to the beach (Falabella et al. 1994:33). However, it is further noted that when estimating the presence, absence or abundance of fish at archaeological sites, the differential survival and recovery of these remains needs to be considered (see Falabella et al. 1994:34; Santoro et al. 2017a).
Another coastal archaeological site, which indicates evidence of marine resource use, is the site of Punta Caraumilla in central Chile. The site of Punta Caraumilla is situated adjacent to the rocky littoral zone of central Chile and has an occupation spanning from the early Archaic Period to the Early Ceramic Period, with evidence of marine resource use throughout the occupation of the site (Jerardino et al. 1992:48; Ramírez et al. 1991). Faunal evidence at the site included remains from sea lions (*Otaria byronia*), camelids (*Lama guanicoe*), penguins (*Spheniscus humboldti*), pelicans (*Pelecanus* spp.), sea otters (*Lutra feline*), 31 species of invertebrates (including molluscs, crustaceans and echinoderms) and various unidentified rodents (see Jerardino 1992; Ramírez et al. 1991). Additionally, archaeological evidence (in the form of stone tools, bone tools and one copper fish hook) indicate exploitation of marine resources through to the Early Ceramic Period (Jerardino et al. 1992:49). However, it has been noted that fish remains at the site are scarce, with further sampling required to assess the importance of fishing in the area (Jerardino et al. 1992:58). Nevertheless, this site represents an example of early marine exploitation of the rocky intertidal area on the central Chilean coast.

Summary

The above examples are not intended to provide an exhaustive list of sites with a maritime influence, but rather, serve as a snapshot of mid-late Holocene coastal archaeological sites in South America and central Chile, providing both a temporal context and a baseline for evidence likely to be found at the Fénix sites in Quintero Bay.

Archaeological evidence indicated that, during the mid-late Holocene in South America, coastal populations were exploiting marine resources to at least some extent, with there being no evidence, to date, of coastal populations not utilising marine resources at all (see Carter 2017; Dillehay 2008; Gaspar et al. 2008; Rostain 2008; Sandweiss 2008; Zangrando 2009). Similarly, from the early Archaic to Early Ceramic Period in central Chile, coastal populations were utilising marine resources, with a heavier exploitation of shellfish and fish during the Early Ceramic Period (see Castro et al. 2016; Falabella and Planella 1991; Jerardino et al. 1992; Olguín 2013; Olguín 2014; Ramírez et al. 1991). While one copper fish hook was found at the site of Punta Caraumilla, there is not significant evidence of a maritime toolkit on the central Chilean coast, with faunal evidence predominantly pointing to the exploitation of vertebrate and invertebrate

species from marine rocky intertidal zones (see Jerardino et al. 1992; Ramírez et al. 1991).

The Adoption of Agricultural Economies

Overview

The move from hunting and gathering to the adoption of agriculture (or mixed economies) largely took place in the first half of the Holocene, between 12,000 to 5000 BP, in different areas around the world (see Binford 1968; Cohen 1977; Fagan 1987; Flannery 1973; Smith 1989, 2006; Weiss et al. 2004). Within only a few thousand years, agriculture was adopted independently in at least seven different regions across the globe and spread rapidly from these areas (Larsen 2002:70). Presently, the earliest evidence of the adoption of agriculture is in the Levant region of the eastern Mediterranean, during the Epipalaeolithic 'Natufian' Period (c. 14,500–11,600 cal BP) (Pinhasi and Stock 2011:2). Agriculture was demonstrated by extensive exploitation of wild grains, the use of grindstones, and organised social structures (see Belfer-Cohen and Bar Yosef 2000; Pinhasi and Stock 2011:2). Similarly, agriculture, in the form of exploitation of wild grains, was demonstrated as early as 13,000 BP at the Anatolian site of Abu Hureya (Hillman et al. 2001; Pinhasi and Stock 2011:2). Further evidence for agriculture in the first half of the Holocene has also been found in Ethiopia, southern China, southeast North America, Meso-America and western South America (Bellwood 2005; Binford 1968; Pinhasi and Stock 2011; Smith 1989, 2006, 2011; Wright 1977; Hu et al. 2006).

Agriculture: An Introduction

Evidence around the world reflects the adoption of agriculture throughout many different societies. In many circumstances the adoption of agricultural practices led to the rise of food production and the storage of surplus food, which in turn led to social hierarchy, technological change and property ownership (Pinhasi and Stock 2011:1). However, it is important to note that the adoption of agriculture was not simply a linear transition from hunting and gathering to agriculture. Indeed, it has been demonstrated

that some societies moved back and forth between hunting and gathering and agriculture to suit their collective needs (see Santoro et al. [2011b] for a Chilean example). Thus, agriculture was a technique that could be employed where geographic, ecological, climatic and cultural conditions permitted and was not necessarily the "next step" that a population could take to "move forward" in society. It is also noteworthy to point out that some populations never adopted agricultural economies and continue a hunter-gatherer way of life (see Lee 1979; Lee and Devore 1968; Price and Brown 1985; Santoro et al. 2005).

The adoption of agriculture has raised many questions for archaeologists over the past few decades. One of the main questions is: Why would hunter-gatherers adopt laborintensive agricultural practices? One of the answers may be that these populations had few resources and needed to supplement part of their diets with agriculture. However, this does not explain why populations with rich coastal resources have been found to show evidence of the adoption of agricultural practices while still having access to terrestrial, marine and lacustrine resources (see Dillehay et al. 2012a; Falabella et al. 2007; Sanhueza and Falabella et al. 2010; Smith 2011). Possible reasons for the adoption of agricultural economies are explored further in sections below.

Despite the adoption of agriculture taking place across the globe, it is unlikely that agricultural practices began the same way, or for exactly the same reasons, in the different geographic regions (see Lynch 1973; McRostie et al. 2017; Rindos et al. 1980). There are several theories that have been proposed about the advent of agriculture and how it would have benefitted populations. One theory about the move to agriculture was Kent Flannery's (1968) theory of seasonality and scheduling. This theory relies on the primary concept that certain plants and animals are only available in particular seasons and that populations knew of which plants/animals were available in which seasons, so they could "schedule" when to go and forage for them. For example, in summer, certain types of plants may flourish, providing the population with an abundance of food but may die out in the winter when another, cold season plant may in turn take its place (Flannery 1968:67). This theory supposes that instead of a population adapting to microenvironments in a selected zone, they range far and wide relying on their knowledge of what plants will be available in which areas (Flannery 1968:67).

It is further assumed that eventually populations would begin to harvest plants in certain seasons and perhaps even start to grow their own plants, leading to seasonal agricultural practices and a more sedentary way of life (see Flannery 1968:81; Harrison 1996). Thus, with agricultural scheduling it was possible for populations to live in one location farming their own plants during the harvest season and spend other less fruitful seasons hunting and gathering (Flannery 1968:82). Following on from early introductory theories concerning precursors to the adoption of agriculture, are several ideas concerning climate change, population pressure and social triggers that may have led to agricultural practices.

Theories Relating to the Adoption of Agriculture

Some of the early hypotheses for the transition from hunting and gathering to agriculture focused on prime catalysts, such as climate change (see Childe 1936, 1952; Willey 1966; Wright 1977) and population pressure (Binford 1968; Cohen 1977). These models were seen as "push models" as they were thought to be evidence that people were pushed or forced to adopt agricultural practices (Price and Bar-Yosef 2011:S168). Other theories, such as social theories (see Bender 1975, 1985; Hayden 2003) are seen as "pull theories", meaning that people were being pulled, or drawn to the benefits of agriculture (Price and Bar-Yosef 2011:S168). In this section, these theories and models are explored with reference to relevant case studies.

Climate Change

Climatic changes, such as sudden severe increases or decreases in temperature and rainfall lasting decades, or even centuries, have been proposed as the impetus for the adoption of agriculture (Willey 1966; Wright 1977). For example, the shift from a continental to Mediterranean climate on the eastern Mediterranean coast created more diverse vegetation, with a dramatic increase in annual cereal grasses that eventually spread across the continent (Weiss et al. 2004:9551).

Another example of a set of favourable conditions for the adoption of agricultural practices was on the coast of Chile, in South America. Chile is situated on a narrow strip along the western edge of the continent, bordering the Pacific Ocean, allowing access to terrestrial, lacustrine and marine resources. However, climatic changes, such as El Niño

Southern Oscillation (ENSO) on the western coast of South America, around 6000 to 5000 BP, affected the marine biomass, changing the available marine resources (see Thiel et al. 2007; Williams et al. 2008) (see Background Chapter for more detail). These changes led to the gradual collapse of entire marine ecosystems, affecting local fisheries. Therefore, it has been suggested that ENSO was a possible triggering mechanism for the move from coastal hunter-gatherer-fishers to inland valley sites and the adoption of agricultural practices (Ramirez et al. 2001:6). Furthermore, according to Williams et al. (2008:248), there was a "critical tipping point" for hunter-gatherer societies along the coast, which led coastal populations to become more reliant on a mixed agricultural/marine economy due to a major collapse of coastal fishing systems after approximately 2500 cal BP (Jenny et al. 2002; Santoro et al 2017; Thiel et al. 2007).

Flannery (1986:10) believes that while climatic changes at the end of the Pleistocene may not have necessarily led to the adoption of agriculture, they did create conditions that were favourable for a suite of new plants to colonise the region, thus, making them accessible for thousands more of the general population. Additionally, climatic conditions also created less favourable conditions for hunter-gatherer-fishers on the western coast of South America.

Population Pressure

Population pressure has also been one of the most popular theories for explaining why prehistoric peoples adopted agricultural practices. It has long been theorised that huntergatherer societies adopted agriculture because greater numbers could not be sustained on the basis of a hunter-gatherer diet (see Boserup 1965). Most theories that rely on the idea that population pressure is the reason that people adopted agricultural practices argue that over time areas with the richest resources filled up and therefore, people had no option but to settle down in areas with less resources. Thus, increasing their reliance on local resources (Fagan 1987:240), which may not have previously been exploited and eventually turning to agricultural practices to more adequately support the population.

Among others, two of the key proposers of the population pressure model were Lewis Binford (1968) and Mark Nathan Cohen (1977). Binford's (1968) theory was based on the question: 'To what degree did man (sic) modify his (sic) behaviour under pressure, because his (sic) existing strategies were failing?' (Binford 1968:196).

Binford (1968:199) argued that the adoption of agriculture involved more time, labour and effort than hunting and gathering and that people would only choose to adopt agricultural practices if they had no other choice or if it was a solution to a problem that they had been facing. Binford's (1968) theory was based around the idea of "density equilibrium". This means that if there was a change in the equilibrium between the population and the environment that resulted in less available food or too many people in one area then people would look to solve this problem (Binford 1968:208). Binford's (1968) theory is that the solution found for this problem was the adoption of agricultural practices (Binford 1968:212). Binford's (1968) hypothesis suggested that humans made a conscious decision to adopt agriculture to ensure that there would be a future food supply.

Similarly, archaeologist Mark Nathan Cohen (1977) hypothesised that strategies for increasing food supply, within the constraints of hunting and gathering, had been exhausted by approximately 10,000 years ago in some parts of the world, thus leaving no alternative but to turn to agriculture. Cohen's (1977) theory was based on the idea that it was worldwide population pressure that caused many hunter-gatherer societies to transition to agriculture, due to the populations reaching the limit of what their food resources could support. For Cohen (1977), the adoption of agriculture was a solution to the problem of overpopulation, however, there is actually very little evidence to support the idea of overpopulation in the record of agricultural origins (Price and Bar-Yosef 2011:S167). Any evidence that has been found for this theory cannot be definitively pinpointed to before or after the adoption of agriculture, leading to the "chicken and the egg" idea of whether overpopulation led to the origins of agriculture or whether the origins of agriculture created population increase.

Binford's (1967) and Cohen's (1977) theories both rely on the idea of human intentionality. The idea that people were consciously looking towards the future and making changes that would ensure they had long-term food supplies, rather than just

modifying their behaviour based on a momentary decision or thought process (Flannery 1986:5).

Supporting Studies for Population Pressure

The population pressure theories suggest that the populations in certain areas were too large to survive on hunting and gathering practices and that the reason for the adoption of agriculture was to solve the problem of getting enough to eat, however, this does not always coincide with evidence found at archaeological sites around the world. One such site is the site of Huaca Prieta, a Peruvian coastal site, with rich mixed maritime and wetland resources. At this site Dillehay et al. (2012b:49) found that the population was practicing various degrees of horticulture. The reason for these practices was not because the population was farming cotton to make fish nets and textiles to improve their fishing (Bird et al 1985; Dillehay 2012b:50). This is one example where the adoption of horticultural practices has been interpreted as supporting technological innovation, rather than a dire need for more food in order to support the population.

Another study, which demonstrates evidence of populations with rich resources adopting mixed-agricultural practices, is Smith's (2011) research on plant domestication in eastern North America. Smith (2011) examined six sites (Napolean Hollow, Riverton, Cloudsplitter Newt Kash, Hayes, Phillips Spring, and Marble Bluff) in eastern North America in the resource rich areas of river valleys, oak-savannahs and oak-hickory forest regions. Smith (2011:S473) found floral and faunal evidence, which indicated the use of a wide range of wild species. At the sites that were analysed there was no evidence of resource depletion or population pressure (Smith 2011:S482), however, plant domestication is still evidenced in these areas. This is another such example of the adoption of agricultural practices by populations that were not suffering the effects of population pressure or resource imbalance.

Additionally, Flannery (1986:11) believes that the population pressure hypotheses cannot be applied to smaller agricultural populations, as they do not fit the profile of the situation. His research into populations in Guilá Naquitz, Mexico, have returned results that are not consistent with the idea of people adopting agriculture due to population

pressures and food shortages (see Flannery 1986). He believes that phrases such as "overpopulation", "foodcrisis" and "exhaust all possible strategies" to describe small populations are exaggerations.

Social Theories

Following early theories citing climate change and population pressure as reasons for the adoption of agriculture, a number of social theories were put forward. These included theories encompassing increasing social complexity and competition (see Bender 1985; Hayden 2003). Advocates for social theories argued that the adoption of agricultural practices cannot simply be explained and understood in terms of environmental and population density pressures. It has been argued that human beings are more complicated than has been portrayed and that there were likely cultural, political and religious reasons for the adoption of agriculture (Price and Bar-Yosef 2011:S167). The idea that surplus food may have been transformed into other more valued items within a society, which lead to class differentiation and social complexity has been explored (Price and Bar-Yosef 2011:S167).

One advocate of a social theory for why populations adopted agriculture was posited by Barbara Bender (1975). Bender's (1985) hypothesis recognises that hunter-gatherer societies were becoming more socially complex, with far more elaborate hierarchical social organisation. She points to the increasing abundance of trade objects and takes this as evidence that an expansion of trade, and of political alliances between neighbouring groups, created new social and economic pressures to produce more and more surplus goods (Bender 1985:53).

One case study that examines Bender's social theory is the case of Dickson's Mounds, Illinois, USA. Motivation by religious leaders or administrators to adopt labor-intensive agriculture may have led to changes in subsistence strategies. Goodman et al. (1984:272) investigated the negative effects of agriculture on the health of a society and found that due to increased population density and sedentism, intensification of maize agriculture, and extension and intensification of trade, the inhabitants of Dickson's Mounds suffered negative health effects (Goodman et al. 1984:272). However, these negative effects were predominantly attributed to the lower classes within the society at Dickson's Mounds. It

was found that, after the transition to agriculture, there was a split in the classes, with the working class' health suffering while the elite class' health was improving (Goodman et al. 1984:300). This was because the working class suffered an increase in skeletal stresses from working in the maize fields, and receiving smaller caloric returns for their production efforts, while the elite benefited from not having to work but still being able to consume the food being produced. Goodman et al. (1984:300) found that due to the excess food being traded to places outside the local system, the population in general did not benefit from the agricultural production. It is possible that the over-dependence on maize agriculture within this rich hunter-gatherer habitat could have been related to religious or political coercion by the upper classes for the lower classes to produce more maize to trade.

Similar to Bender's (1985) theory, is Hayden's (2003) social competition hypothesis, which proposes that competition within hunter-gatherer societies may have been one of the causes of the transition to agriculture. Hayden (2003) believes that ambitious individuals wanting to acquire prestige and social standing by throwing feasts may have created competition between groups, leading to the eventual adoption of cultivation to provide supplies for these events. One example of this is evidence from an archaeological site in the central Andes of Peru. Stable carbon and nitrogen isotope research found that the males in the population were in better health than the females, likely from consuming more maize in ritual feasting ceremonies (Hastorf 1985:21). This is an example of agricultural practices being used for social standing within a population.

Social hypotheses introduce another element to the continuing argument of why huntergatherers adopted labor-intensive agricultural practices. One complication with these theories is that it is hard to differentiate whether the reorganisation of social relations led to the adoption of agricultural practices or the reorganisation of social relations was a consequence of the adoption of agriculture (Price and Bar-Yosef 2011:S167). Social theories also fail to consider that many early Holocene hunter-gatherer societies were more complex and pre-adapted to food production before the adoption of agricultural practices. By using a multivariate model to encompass key aspects of these theories, the transition from hunting and gathering can be more thoroughly explored.

The Adoption of Agriculture in South America

The adoption of agricultural economies in South America developed during the early Holocene across the continent, with different domesticates originating in distinctive environments (see Pearsall 1992; Pearsall 2008:105; Perez et al. 2017). The northern regions of South America, such as Colombia and Ecuador, show evidence for the origins of treecrops, tuber and squash domestication (see Pearsall 2008; Perez et al. 2017). The central and eastern regions of South America, such as Brazil and Argentina, demonstrate evidence for early origins of legumes, lowland roots, and tubers (see Pearsall 2008; Perez et al. 2017). The western regions of South America, such as Peru and Chile, illustrate further expansion of central Andean domestication, with evidence for the origins of pseudocereals and mid-high elevation roots and tubers (see Pearsall 2008; Perez et al. 2017). Additionally, maize adapted to a broad range of habitats in South America, with DNA studies indicating that the maize subspecies Balsas teosinte gave rise to domesticated maize (Pearsall 2008:106). However, Balsas teosinte is thought to have its origins in the tropical forests of western Mexico, suggesting the spread of maize out of Mexico and into South America (Pearsall 2008:106) (Figure 2.14).

Agricultural Practices in Northern South America: Colombia and Ecuador

Archaeological evidence for the early domestication of tree crops and tubers has been found in the northern region of South America. Arrowroot (*Maranta arundinacea*) starch recovered from the site of San Isidro (10,000–9489 BP), along with palms, such as *Acrocomia* were found in the upper Cauca Valley of Colombia (see Pearsall 2008:110; Zeidler and Pearsall 1994). Additionally, in the Calima region of the middle Cauca Valley, arrowroot family phytoliths and macroremains (such as palm and *Persea*), were found alongside archaeological artefacts (such as grindstones and hoes) at the sites of Sauzalito (c. 9620–9500 BP) and El Recreo (c. 7930–7730 BP) (see Drennan 2008:390). Maize was also documented in the Cacau Valley area, from pollen cores dating to 5100 BP at the site of Hacienda Lusitania, 6630 BP at the site of Hacienda El Dorado and c. 8127–5160 BP at the site of Paramó de Peña Negra I (see Pearsall et al. 2004; Zeidler 2008).

In Ecuador, squash phytolith cores were found in coastal Ecuador around 9690 BP (Pearsall 2008:110). Additionally, maize phytolith cores were found dating to 6950 BP at Vegas sites (see Stothert 1985), 5450–3750 BP at the site of Real Alto and 4950–3950 BP

(see Chandler-Ezell et al. 2006; Klepinger 1979; Ubelaker 2003) at the site of Loma Alta (see Presley 1982). By 4750–4350 BP maize is widespread throughout the area, with achira, manioc and arrowroot also being documented in the area (see Pearsall et al. 2004; Pearsall et al. 2008:110).

Agricultural Practices in Eastern South America: Brazil and Argentina

To the east of South America, legumes, such as the peanut (*Arachis hypogaea*), the jack bean (*Canavalia plagiosperma*), the common bean (*Phaseolus vulgaris*), the lima bean (*Phaseolus lunatus*) and lupine (*Lupinus mutabilis*) were domesticated (see Pearsall 2008). Research into the plant manioc (*Manihot esculenta*) suggests that it likely originated in the *cerrados* of central Brazil or seasonal forests of Venezuela (Pearsall 2008:106).

At the site of Huachichocana ChII, Valliserrana Region of Argentina, evidence for capsicum, common bean and maize were recovered from strata dated to between 9620 and 8670 BP (Pearsall 2008:112). Additionally, artefact-based residue analyses revealed that tools from sites dating before 5350 BP from Cueva Salamanca I and Quebrada Seca 3, contained pulse and grass residues (see Babot 2004). Furthermore, nine tools from three sites dating to between 5350 and 3150 BP contained residues of maize, quinoa, amaranth, *oca*, *ullucu*, achira, potato and gourd (see Babot 2004: Pearsall 2008).

Agricultural Practices in Western South America: Peru

Archaeological and palaeobotanical evidence for early plant domestication has been found along the Andes, from northern South America (the Colombian Andes), south to the Peruvian Andes (Pearsall 2008:110). Sites such as Tres Ventanas Cave contained macroremains of potato, manioc, sweet potato, *ullucu* and *jicama* dated between 9950 and 7950 BP (see Engel 1970; Ugent et al. 1982). Additionally, between 9950 and 9450 BP, *oca*, capsicum and *lúcuma* remains were found at Guitarrero Cave in northern Peru (see Kaplan 1980; Lynch et al. 1985). Furthermore, macroremains from the Ayacucho Caves indicate the presence of gourd, quinoa, beans, *lúcuma*, coca, potato, maize and capsicum from between 7750 and 3700 BP (see MacNeish 1970).

Along the Peruvian coast, domesticates such as the bottle gourd have been found at Siches Complex Sites from strata between 7950–5950 BP (See Richardson 1978). The site of La Paloma also demonstrates evidence of gourd, squash, guava and beans from strata between 7650 and 4950 BP (see Weir and Dering 1986).



Figure 2.14 Areas of origin of domesticated plants. Map adapted from Pearsall (2008).

The Andes mountain range runs from Venezuela, in northern South America, through Colombia, Ecuador, Peru, Bolivia and Chile. It encompasses deserts, tropical forests and high elevation environments, leading to an equally diverse array of cultivated plants (see Pearsall 2008; Piperno and Pearsall 1998; Sauer 1993, Smartt and Simmonds 1995). Sardi and Béguelin (2011:429) note that the expansion of plant and animal domestication

throughout the Andes and down the Pacific coast was 'through contacts among populations'. Accordingly, along the west coast of South America, the adoption of agricultural practices can be mapped from southern Peru, through to northern Chile.

Northern Chile and Southern Chile (Patagonia)

The adoption of agricultural practices in northern Chile is evidenced by both archaeological and palaeobotanical remains. By 6950 cal BP, cultivation of the following crops took place across Chile: maize (*Zea mays*), beans (*Phaseolus vulgaris* and *Phaseolus lunatus*), gourd (*Lagenaria siceraria*), squash (*Cucurbita ficifolia*), capsicum (*Capsicum spp.*), quinoa (*Chenopodium quinoa*), potato (*Solanum tuberosum*) and guava (*Psidum guajava*) (Cowen et al. 2006:188).

Good indications of cultivated crops, including capsicum (*Capsicum* spp.), beans (*Phaseolus* sp.), potatoes (*Solanum tuberosum*) and squash (*Cucurbita ficifolia*) were also recovered at sites in the same area (Pearsall 2008:112). Cotton, quinoa (*Chenopodium quinoa*) and gourd (*Lagenaria siceraria*) also occur in levels dating from approximately 4450 to 1949 BP at sites such as Quiani II (see Willey 1971) and Tulán Cave (see Popper 1977) (Figure 2.15).



Figure 2.15 Map of northern Chilean sites, referred to in the text, with evidence of plant domestication. Map adapted from Cowan et al. (2006); Grosjean et al. (2007); Santoro et al. (2005).

It has been suggested that the earliest agricultural sites in Chile were associated with marginal environments, such as the Atacama Desert of northern Chile, to supplement the available food sources (see McRostie 2014; Núñez et al. 2009; Santoro et al. 2005). However, even in marginal environments, there is still evidence for the continued practice of hunter-gatherer subsistence methods after the introduction of cultigens into the diet throughout Chile (see Falabella et al. 2007; Petruzzelli et al. 2012; Roberts et al. 2013; Sanhueza and Falabella 2010).

One case of this was demonstrated in the north of Chile at the sites of Azapa 71 and Pica-8. Petruzzelli (2012) found that agricultural practices were still being supplemented by hunting, gathering and fishing as far as 90 kilometres inland during the mid-Holocene in the Atacama Desert. Santoro et al. (2005:256) note that marine collecting, fishing, plant collection and hunting were important aspects of the diets of the people of the inland Atacama until later times, and often complemented an agricultural diet (see Falabella et al. 2007; Roberts et al. 2013; Sanhueza and Falabella 2010).

Furthermore, in the Patagonia region of southern South America, there is currently no evidence of early agricultural practices, with the population relying on hunting, gathering and fishing until historical times (see Borrero and Barberena 2006; Borrero et al. 2009; Yesner 1996; Zubimendi et al. 2015).

Central Chile

The adoption of agricultural practices in central Chile began during the late Archaic Period (c. 10,000–2200 BP) with the domestication of wild plants (such as *Chenopodium quinoa*), and spread throughout the Early Ceramic Period (c. 2200–1000 BP) with maize-based (*Zea mays*) agriculture becoming prominent and gaining importance during the Late Intermediate and Late Periods (c. 1000–400 BP) (see Falabella et al. 2007, 2008; Sanhueza and Falabella 2010; Sanhueza et al. 2003) (Figure 2.16).



Figure 2.16 Map of central Chilean sites with evidence of plant domestication. Map adapted from Falabella et al. (2007); Planella et al. (2014); Sanhueza and Falabella (2010).

However, despite the introduction of cultigens into the lifeways of these early central Chilean populations, there were still populations practicing hunting, gathering and fishing throughout these periods, demonstrating that agricultural practices were not merely a one way "advancement" but were a gradual incorporation and something that could be used in conjunction with other subsistence methods (Sanhueza and Falabella 2010:128; Sanhueza et al. 2003).

Archaic Period Agricultural Practices (c. 10,000-2200 BP)

One of the earliest known sites containing evidence of agricultural practices in central Chile, is the late Archaic site of Las Morrenas 1, located in the Andean basin of the Maipo River (see Cornejo and Sanhueza 2011; Planella et al. 2005). Archaeobotanical remains of quinoa (*Chenopodium quinoa*) found throughout the occupation sequence of the site, dated from between 3250–2980 cal BP (Planella et al. 2005:62). The presence of these remains, found in hunter-gatherer occupation sequences, revealed the possibility of the early introduction to agricultural practices in the Andean cordillera basin in central Chile.

Evidence of similar morphological characteristics between the quinoa found at the site of Las Morrenas 1 and Early Ceramic sites (see Planella and Tagle 2004), make it possible that the quinoa found at the site was cultivated and not wild (Planella et al. 2005:71). However, further research into more Archaic Period sites in the Andean cordillera basin is called for in order to produce more results for comparison (Planella et al. 2005:72).

Another site, which includes archaeobotanical evidence of quinoa (*Chenopodium quinoa*) remains is the site of El Plomo, located in the Alto Maipo (Andean highlands) 2070 m above sea level (see Planella et al. 2011). The site contained several charred and dried quinoa remains, indicating the possible introduction of cultigens into hunter-gatherer lifeways at the site between 3460 and 3340 cal BP (Planella et al. 2011:200). This is another interesting Archaic Period site in which the remains of cultigens have been found in an area of hunter-gatherer occupation, indicating the possible incorporation of cultigens into hunter-gatherer society before the onset of the Early Ceramic Period (Planella et al. 2011:200).

Early Ceramic Period Agricultural Practices (c. 2200–1000 BP)

During the Early Ceramic Period there was an increase in food production throughout central Chile (Falabella et al. 2007, 2008; Sanhueza and Falabella 2010). This period witnessed the development of an economy based on surplus goods, such as maize, pepper, potatoes, quinoa and guano (Falabella et al. 2007; Rivera 1991; Sanhueza and Falabella 2010). Sanhueza and Falabella (2010:133) point out that despite the appearance of pottery in the Initial Early Ceramic Period populations, it is not directly associated with widespread agricultural practices in central Chile. Rather, agriculture during the Initial Ceramic Period seems to have been restricted to quinoa, with no evidence of maize found at the sites (Sanhueza and Falabella 2010:133). Sites such as Lenka Franulic (see Planella et al. 2006), Lonquén (see Falabella et al. 2007), El Mercurio (see Falabella et al. 2007) and La Granja (see Planella and Tagle 1998; Planella et al. 2007) demonstrated archaeobotanical evidence of agricultural practices.

Plant and animal domestication further spread during the Early Ceramic Period (c. 2200– 1000 BP) with the introduction of the Llolleo culture and the beginning of maize (*Zea mays*) agriculture (see Falabella et al. 2008). Archaeobotanical evidence in central Chile attribute the adoption of maize-based agriculture to the mid-Early Ceramic Period, after approximately 1750 BP (Falabella et al. 2008:25).

The Llolleo cultural group were a sedentary society that incorporated maize-based agriculture into their subsistence techniques, relying heavily on maize as an important dietary resource (Falabella et al. 2008:25; Sanhueza and Falabella 2009). It is of further note that maize-based agricultural practices were contemporaneous with quinoa horticulture and hunting and gathering, illustrating a regional picture of the coexistence of hunter-gatherers and agriculturalists during the Early Ceramic Period (Falabella et al. 2007; Falabella et al. 2008; Sanhueza and Falabella 2010). This is reflected by the Bato cultural group, who were contemporaneous with the Llolleo cultural group but were highly mobile hunter-gatherers, who did not appear to adopt maize-based agricultural practices (Falabella et al. 2007:22).

Late Intermediate Period Agricultural Practices (c. 1000-550 BP)

The Late Intermediate Period (c. 1000–550 BP) saw the introduction of the Aconcaguan cultural group and an increase in the importance of maize-based agricultural practices (Falabella et al. 2007, 2008). The Aconcagua cultural phase saw the expansion and consolidation of horticulture (Massone et al. 1998), causing effects and modification in economic activity, pottery production, customs, social habits and food consumption (Planella et al. 2014:510). An example of this is evidenced by changes in architecture, with the addition of large congregation spaces associated with maize consumption at sites such as Cerro la Cruz in the Aconcaguan Valley (Planella et al. 2014:512).

Furthermore, Late Intermediate Period residential sites, such as Huechún 3, Puangue and Villa Cardenal Silva Henríquez all owned large channel mills, which have been perceived to demonstrate large scale production of corn flower and contain remains of quinoa and maize (Planella et al. 2014:509). Additionally, the palaeobotanical evidence (quinoa and maize husks) indicates a general increase in the size of the specimens (compared to earlier samples) and greater variety, implying a more constant and widespread use of the cultigens within the population during these periods (Planella et al. 2014:509).

Late Period Agricultural Practices (c. 550-400 BP)

The Late Period in central Chile saw the influence of the Inka empire in the inland and valley sites. Inka occupation of the coast is currently circumstantial, at best, with there being no adult Inka skeletal remains available for analysis (Falabella et al. 2007:21). Archaeological evidence of Inka contact at sites such as Villa Galilea, Las Tinajas de Quilicura, Nos, Linea 5 Metro and Carrascal 1 is based on ceramic remains with patterns and form assigned to the Inka Period (Falabella et al. 2007:21).

Archaeobotanical evidence, in the form of charred and dried plant remains, indicates the importance of horticultural practices, particularly the prominence of maize in Inka society. Additionally, ethnographic evidence in central Chile suggests the significance of maize-based agriculture, with irrigation and canal systems and an abundance of land with maize cultivation recorded by the Spanish in the 16th century (Falabella et al. 2007:8).

One Late Period site that displayed evidence of the storage and organisation of agricultural products is the site of the Ojos de Agua Tambo, located on the Juncal River. The Tambo is a rest and supply station along the road to a mountain pass which connects with the Uspallata Valley in Argentina (see Garceau et al. 2010). Within the structure, archaeological and palaeobotanical evidence was discovered in the form of large storage pots and macrobotanical remains of cultivated plants such as quinoa, maize, squash chili and wild plant specimens. Planella et al. (2014:512) propose that this station was used to provision food caravans along the road. However, not all Late Period sites associated with the road network contained cultivated plant remains, with some only storing wild provisions (Planella et al. 2014:512).

As mentioned previously, there are various possible reasons as to why cultivated plants would be incorporated into hunter-gatherer lifeways in South America. The factors that led to the domestication of plants and animals remain unclear, however, evidence in central Chile suggests that low resource availability and/or population growth were not the major causes for the shift in subsistence strategy (see Falabella et al. 2007; Falabella et al. 2008; Perez et al. 2017; Sanhueza and Falabella 2010; Sardi and Béguelin 2011). Social pressures (political or religious) may have led to the production of surplus goods,

exotic goods and symbols of power within populations. However, it is difficult to know for certain whether these mechanisms were in place or not in Chilean society.

The Archaeology of Agriculture

The introduction of agricultural practices can be mapped though the relative material evidence at archaeological sites, however traditional techniques used to assess diet and resource use are not ideal as they only show the amounts of materials that are left behind over time and may not necessarily represent the full picture of past human resource and landscape use at a site. Additionally, using artefacts from archaeological sites as evidence of the introduction of agriculture can be difficult, as it is likely that the same tools were used before agriculture and adapted for different purposes (Steward 1933:233). This was pointed out by American anthropologist, Julian Steward, who conducted research into the use of irrigation by hunter-gatherers in the Owens Valley, eastern California. Steward (1933:233) found that hunter-gatherers in Owens Valley were using irrigation to foster the growth of wild grasses, which could be misinterpreted by archaeologists as an indication of "agriculture". Steward (1933:233) further noted that the population from Owens Valley also used ceramics. Therefore, the idea that ceramics are direct evidence of agricultural practices is erroneous, as ceramics may just be an indication of more sedentary lifeways (Sanhueza and Falabella 2010; Sassaman et al. 2006).

One issue with a traditional archaeological approach that employs the presence of certain artefacts (e.g. ceramics and textiles), as an indication of the presence of agricultural economies, is that those artefacts may also be present in hunter-gatherer societies and more sedentary societies that did not adopt agricultural practices. Direct evidence, such as the presence of floral remains, may be taken as an indication of the use of cultivated plants. However, palaeobotanical evidence cannot tell archaeologists the quantities consumed by individuals at the site. This is where archaeological chemistry is particularly useful, as isotopic and elemental analyses can measure the types and amounts of food originally consumed by an individual and can therefore lead to a clearer picture of what kinds and the relative quantity of foods these people were eating, and whether these foods were the produce from a maize-based agricultural economy (see Literature Review Part Two).

Summary

The adoption of agriculture took place around the same time across the globe. Archaeologists have attempted to develop a universal theory explaining the adoption of agriculture by societies around the world. However, there is, as yet no one accepted theory, with the consensus largely being that the adoption of agricultural practices was locally/regionally driven and reliant on a range of reasons including, but not limited to, environmental, cultural, social and political factors.

The adoption of agriculture in South America can be mapped from southern Peru through to northern Chile and into central Chile (see Falabella et al. 2007; Sanhueza and Falabella 2010; Santoro et al. 2005). Agricultural practices in central Chile began with the appearance of quinoa remains in the mid-late Archaic Period (c. 6000–2200 BP), spreading through the Llolleo cultural complex with the introduction of maize-based agricultural practices during the Early Ceramic Period (c. 2200–1000 BP) and into the Late Intermediate Period and Late Periods (c. 1000–400 BP) with the intensification of agriculture through the Aconcaguan and Inkan cultural groups (see Falabella et al. 2007; Falabella et al. 2008; Planella et al. 2014).

Chapter Summary

This part of the literature review has examined human diet and landscape use in global, regional and local contexts through archaeological analyses, providing contextual data for the archaeological aspect of this research project. This section explored the key theories behind hunter-gatherer-fishers and agricultural resource use, allowing an understanding of the archaeological background to this research.

Isotope and Elemental Analyses: An Introduction

Stable isotope and elemental analyses of human and faunal bones derived from archaeological contexts have been widely used in archaeology to investigate a diverse range of environmental and cultural variables including aspects related to palaeodiet and palaeomobility (see Ambrose 1991, 1993; DeNiro and Epstein 1978, 1981; Katzenberg and Harrison 1997; Longinelli 1984; Luz et al. 1984; Makarewicz and Sealy 2015; Pate 1994, 2008a, 2008b; Price 1989; Schoeninger and Moore 1992; Sealy et al. 1995; van der Merwe 1982).

Isotope and elemental analyses of human skeletal material have become particularly useful for archaeologists as they allow improved quantitative estimates of proportions of dietary components, which were formerly very difficult because food remains are not preserved and recovered in the portions that they were consumed (Ambrose 1993:59). Over the last 40 years, isotope and elemental analyses of human material remains have successfully explored theories concerning, but not limited to, marine versus terrestrial resource use (see DeNiro and Epstein 1978, 1981; Falabella et al. 2007; Richards et al. 2003; Schoeninger et al. 1983; Schoeninger and DeNiro 1984; Sealy and van der Merwe 1986; 1988; Tauber 1981; Vogel and van der Merwe 1977; Walker and DeNiro 1986; Yesner 1988), the adoption, or not, of agricultural practices (see Falabella et al. 2007; Falabella et al. 2008; Hedges and Reynard 2007; Koch 2007; Sanhueza and Falabella 2010), human landscape use and mobility (see Budd et al. 2004; Ehleringer et al. 2008; Levinson et al. 1987; Longinelli 1984; Luz et al. 1984; Moser et al. 1972) and post-mortem contamination (see Collins et al. 2002; Hedges 2002; Henderson et al. 1983; Nelson et al. 1986; Pate and Hutton 1988; Price et al. 1992). Thus, isotope and elemental analyses have allowed a more detailed and reliable reconstruction of past lifeways, climate and ecology.

Isotopic analyses in this context work on the premise that signatures in food and water from particular geographic regions are recorded in the tissues (bone, teeth,

nails, hair etc.) of the consumers (Ambrose 1991; Beard and Johnson 2000; Pate 1994; Pate 2008b:177). This is because the chemical composition of water, sediments, plants and animals vary across different marine and terrestrial environments (see Ambrose 1991; Ambrose and DeNiro 1986; Heaton et al. 1986; Pate and Anson 2008; Sealy et al. 1987). Additionally, a large number of trace elements, which vary in concentrations across distinct geographical environments, are incorporated into human tissues in relation to environmental exposure and consumption (see Castro et al. 2010; Pate 2008a; Price 1989; Priest and van de Vyer 1999; Reynard and Balter 2014). This is because distinct elemental values in soils and plants are passed up the food chain to animals and humans (see DeNiro and Epstein 1978, 1981; Katzenberg 2000; Tieszen and Boutton 1988).

In order to effectively determine human diet and landscape use through isotopic and elemental analyses, it is necessary to first establish baseline chemical signatures for the environment of the study area (see Schoeninger et al 1983; Schoeninger and DeNiro 1984). Once the baseline values have been established, a comparison of human isotope and elemental values can be compared to that of the environment to reconstruct past cultural landscapes and form hypotheses regarding the diet and landscape use of individuals/populations.

Isotope Analysis Biogeochemistry

Introduction

The term isotope was first used by the Scottish chemist, Fredrick Soddy, to describe his observation that atoms with different atomic masses have similar chemical properties (Price and Burton 2012:90). Today, we understand that isotopes are two or more forms of the same element, which contain equal numbers of protons but different numbers of neutrons in their nuclei (Ambrose 1993:64). As the number of protons in the atomic nucleus defines the chemical properties of an element, the same element may have several possible masses, or isotopes

(Price and Burton 2012:90). Additionally, different isotopes of the same element may have a different number of neutrons in the atomic nucleus, changing the weight of the element, but not the chemical properties (Price and Burton 2012:98).

Isotope composition can be expressed in terms of delta values (δ), which are parts per thousand (∞) differences from a standard. The number of various isotopes that are in a sample are expressed as:

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

where X represents the isotope and R represents the ratio of the isotope and its natural form (i.e.,¹³C/¹²C) (Peterson and Fry 1987:294). International standards are used as a baseline comparison for isotope measurements to allow for international comparison between isotope values. Carbon isotopes are commonly measured against the marine carbonate Pee Dee Belemnite ($_{PDB}$), nitrogen isotopes are measured against atmospheric N₂ ($_{AIR}$), and oxygen isotopes are measured against Standard Mean Ocean Water ($_{SMOW}$) (see Malainey 2010).

In biogeochemistry, different isotopes are analysed to obtain different information about the human skeleton and compared with baseline data from the environment. An example of this is comparing ¹³C/¹²C isotopes in bone collagen against ¹³C/¹²C isotopes in plant matter and faunal collagen to examine components of human dietary intake (O'Leary 1988). Many different elements can be used for different analyses of the human skeleton and prehistoric human behaviour. The measurement, and subsequent comparison, of isotope delta values allows a distinction to be made between the consumption of various plant types, terrestrial and marine animals, and sources of food and water (see Ambrose 1993; Ambrose and Krigbaum 2003; DeNiro 1987; Luz et al. 1984; Pate 2000).

Carbon and nitrogen isotopic analyses are used to distinguish between temperate and tropical plant types, and marine versus terrestrial resource use, in addition to providing information about trophic level and occupation of arid-habitats (see DeNiro 1987; Pate 2000; Roberts et al. 2013; Vogel and van der Merwe 1977). Additionally, oxygen and strontium isotope studies have been widely used for provenance studies, through an examination of human isotopic values in comparison with local water and soil values (see Knudson 2009; Knudson and Price 2007; Knudson et al. 2012a, 2012b; Luz et al. 1984; Moffat 2013).

Other isotopic studies, such as those on sulphur, lead and hydrogen have also been conducted in relation to an examination of prehistoric subsistence techniques (see Budd et al. 2004; Müller et al. 2003; Richards et al. 2003; Rubenstein and Hobson 2004; Pate 2008a, 2008b). However, while the field of isotopic research in studies of past populations is always expanding, this project focusses on carbon, nitrogen and oxygen isotope analysis of human bone collagen and carbonate to examine the diet and mobility of prehistoric Chilean populations. As such, this section will focus primarily on the application of carbon, nitrogen and oxygen studies on human skeletal material.

Chemical Dietary Studies: Stable Carbon and Nitrogen Isotope Analysis

Carbon Isotopes

Carbon contains one radioactive (¹⁴C) and two stable isotopes (¹³C/¹²C); with ¹²C being almost 100 times more abundant than ¹³C (Malainey 2010:35). Organic carbon (C) is present throughout the environment, with the addition of inorganic carbon in the atmosphere, as carbon dioxide (CO₂) and carbon monoxide (CO). Carbon occurs in soils, carbonate rocks (such as chalk and limestone), fossil fuels (such as oil, natural gas and coal) and is a key component of living organisms (in carbohydrates, fats and proteins) (Malainey 2010:35) (Figure 2.17).



Figure 2.17 The carbon cycle. Image adapted from Malainey (2010:36).

An examination of the carbon cycle and carbon concentrations in living organisms allows for the study of human diet through stable isotopic analysis of human bone. Variations in carbon isotope values are useful for distinguishing diet and/or palaeoclimate due to the existence of three different photosynthetic pathways in plants (see Lee-Thorp et al. 1989; O'Leary 1988; Pate 1994; Schoeninger and Moore 1992).

The first of these three photosynthetic pathways is called the Calvin cycle (C₃) and includes plants such as temperate shrubs, trees and some grasses living in cooler climates (Bassham 2003; Bassham et al. 1950). These plants produce glycerate 3phosphate (a three-carbon compound) during the "dark stage" of photosynthesis, resulting in more negative δ^{13} C values in consumer tissues (Bassam et al. 1950; Lee-Thorp et al. 1989; O'Leary 1988; Pate 1994; Schoeninger and Moore 1992). The second photosynthetic pathway is called the Hatch-Slack enzymatic pathway (C₄) and includes tropical and arid adapted grasses and herbs, as well as maize (see O'Leary 1988:330; Hatch 2002; Slack and Hatch 1967). Plants using the Hatch-Slack pathway produce oxaloacetate (a four-carbon compound) during the "dark stage" of photosynthesis (see Hatch 2002; Toole and Toole 1992) and therefore result in more positive δ^{13} C values in an individual's diet (see Lee-Thorp et al. 1989; O'Leary 1988; Pate 1994; Schoeninger and More 1992). Finally, the third photosynthetic pathway is called the Crassulacean Acid Metabolism (CAM) pathway. Plants using the CAM pathway close their stomata during the day and open it at night to collect CO₂ (Herrera 2008; Ranson and Thomas 1960; Ting 1985). The CO₂ is then stored at night, as the four-carbon acid malate, and transported to the chloroplasts where it is converted back to CO₂, to be used during photosynthesis. This photosynthetic pathway is primarily used in arid environments by drought resistant plants (such as cacti, agaves and pineapples) (see Herrera 2008; Ting 1985). The CAM pathway is frequently excluded from palaeodietary studies because CAM species are rarely eaten by herbivorous animals and therefore rarely enter food chains involving humans (Grocke 1997; Herrera 2008; Owen 2003:9).

Carbon isotope values from each of these different plant pathways are passed up through consumer tissues (after fractionation) and can demonstrate a positive or negative correlation with baseline plant values within an environment. Thus, human carbon isotope values can be matched with baseline values from the plants using these different photosynthetic pathways and tell us what individuals from a population were eating (Price and Burton 2012:92). More subtle variations in δ^{13} C values in exclusively C₃ environments have also been used to distinguish between closed forested habitats and more open and drier environments (see Ecker et al. 2013).

Bone collagen δ^{13} C values range between approximately -5‰ and -25‰, with the more positive (-5‰) indicating a predominantly C₄ based diet and more negative (-25‰) indicating consumption of primarily C₃ foods (see DeNiro and Epstein 1978; Price and Burton 2002; Schoeninger et al 1983; Tykot et al. 2009; Vogel and van der Merwe 1977). However, there are two key sources of variations in δ^{13} C in human diets. The first is, as mentioned above, different ratios of carbon in the kind of plants consumed, and the second is different ratios of carbon between terrestrial and marine foods (see Chisholm et al. 1982; Schoeninger et al. 1983; Tauber 1983). Studies into the differences between δ^{13} C bone collagen diet-to-tissue

 $(\delta^{13}C_{d-col})$ fractionation is +5.1‰, though it can be higher or lower depending on $\delta^{13}C$ values between protein and energy sources and the proportion of protein in the total diet (see Ambrose and Norr 1993; DeNiro and Epstein 1978; Jim et al. 2006; Tykot 2004; Tykot et al. 2009). Furthermore, as bone collagen is biased towards the protein component of the diet, underrepresentation of lipid and carbohydrate portions in the diet result, whereas bone apatite is representative of the $\delta^{13}C$ in the whole diet (see Ambrose and Norr 1993; Tieszen and Fagre 1993).

Research into diet to apatite spacing has found that the mean δ^{13} C bone apatite diet-to-tissue ($\delta^{13}C_{d-ap}$) fractionation is around +9.5‰ but can range between +8.0‰ and +14‰ according to experimental research (see Ambrose and Norr 1993; Bocherens 2000; DeNiro and Epstein 1978; Howland et al. 2003; Krueger and Sullivan 1984; Lee-Thorp et al. 1989; Passey et al. 2005; Tieszen and Fagre 1993). Bone apatite δ^{13} C values are enriched, compared to those in bone collagen, with the difference in the enrichment between bone collagen and bone apatite values being called the collagen to apatite spacing (col-ap) (see Ambrose et al. 2003; Ambrose and Norr 1993; Fernandes et al. 2012; Lee-Thorp et al. 1989). However, the spacing between collagen and apatite values is not constant and is affected by variable factors, such as trophic level differences (see Kruger and Sullivan 1984), and different isotopic signatures of protein and carbohydrate sources (see Ambrose and Norr 1993; Lee-Thorp et al. 1989).

Studies in collagen to apatite spacing have found that the average δ^{13} C collagen to apatite value is +7‰ for herbivores and +3–4‰ for carnivores (see Fernandes et al. 2012; Krueger and Sullivan 1984; Lee-Thorp et al. 1989). Thus, humans following a high protein, high fat diet (such as hunters) will likely demonstrate values closer to those for carnivores and humans following a low protein, low fat diet (such as farmers) will likely demonstrate values closer to those for carnivores and humans following a low protein, low fat diet (such as farmers) will likely demonstrate values closer to those for herbivores (see Ambrose 1992; Krueger and Sullivan 1984; Lee-Thorp et al. 1989).

Lastly, a comparison of modern plant values against archaeological plant values requires correction due to the Suess Effect. The Suess Effect is the name given to the depletion in the isotopic proportions of atmospheric carbon from the mixing of atmospheric carbon and carbon from the burning of fossil fuels (see Keeling 1979). A standard correction of +1.5‰ is applied to modern plants allowing for comparison to archaeological specimens (see Keeling 1979).

Nitrogen Isotopes

Nitrogen contains two stable isotopes ($^{15}N/^{14}N$). While ^{14}N is the most common (at 99.63 % in nature), ^{15}N is also present in smaller quantities (at 0.37%) (Price and Burton 2012:93). Nitrogen is a component of amines, amides and amino acids, which allow living organisms to build protein (Price and Burton 2012:93). The earth's atmosphere is largely composed (79%) of molecular nitrogen (N₂), however, few organisms can use it in its original form. For nitrogen to be used by living organisms, it needs to be converted into nitrates and other compounds; a process known as fixation (see Price and Burton 2012; Unkovich 2013; Vitousek et al. 2002). Biological N₂ fixation is the assimilation of atmospheric N₂ into ammonia (NH₃) by specialised microorganisms (diazotrophs), and a key entry point for atmospheric nitrogen (N) into terrestrial ecosystems (see Unkovich 2013; Vitousek et al. 2002). Nitrogen fixation, by diazotrophs, allows nitrogen to enter other living organisms, such as plants, animals and humans (see Malainey 2010; Unkovich 2013; Vitousek et al. 2012) (Figure 2.18).



Figure 2.18 The nitrogen cycle. Image adapted from multiple sources (see Malainey 2010; Price and Burton 2012).

Bianca Waldie

Nitrogen in terrestrial plants is split into three isotopic categories: nonleguminous plants, leguminous plants and marine plants (Owen 2003:9). These three nitrate sources create a difference in the isotopic composition of the plant, which is thus reflected as a difference in δ^{15} N isotopic values (Price and Burton 2012; Unkovich 2013; Vitousek et al. 2012). The first, non-leguminous plants, derive all their nitrates from the soil around them, where a series of reactions by free-living bacteria convert ammonia to nitrates (Owen 2003:9; Unkovich 2013; Vitousek 2002). Stable nitrogen isotopic values for non-leguminous plants have been found to be around +5% (see DeNiro and Hastorf 1985). The second, leguminous plants, contain nitrogen fixing bacteria in their roots and have isotope values ranging between +0‰ and +4‰ (see DeNiro and Hastorf 1985; Handley and Raven 1992; Owen 2003:9). Finally, marine plants obtain their nitrogen primarily from nitrates dissolved in seawater (see Unkovich 2013; Vitousek 2002). Nitrogen isotopic delta values are substantially enriched in marine environments, compared to those from terrestrial environments, with values ranging from between +11‰ to +27‰ (see Mays 1998; Petruzzelli et al. 2012; Roberts et al. 2013; Schoeninger and DeNiro 1984).

Nitrogen in living organisms allows for the study of marine versus terrestrial resource use through stable isotopic analysis of human bone collagen (see Chisholm et al. 1982; Schoeninger and Moore 1992; Schoeninger et al. 1983; Tauber 1981). Nitrogen isotopic distinction is possible due to the differing ratios of 15 N/ 14 N in nature, which are measured using a mass spectrometer (Price and Burton 2012:93). These ratios are used to distinguish between trophic levels and the importance of marine foods in a consumer's diet (Price and Burton 2012:93).

Nitrogen reported as δ^{15} N in palaeodietary studies, ranges from approximately -5‰ to +27‰, with more positive values reflecting a higher trophic level (+3‰ for each trophic level between consumers), or the consumption of marine foods (see Chisholm et al. 1982; Pate 1995; Petruzzelli et al. 2012; Roberts et al. 2013; Schoeninger and Moore 1992; Schoeninger et al. 1983; Tauber 1981). Furthermore, biological and environmental factors have been known to influence δ^{15} N values, with cases of crop fertilisation (see Bogaard et al. 2007; Bogaard et al. 2013; Fraser et al. 2011; Szpak et al. 2012) and arid environments promoting the enrichment of δ^{15} N values (see Anson 1997; Pate et al 1988; Pate and Anson 2008; Heaton 1999; Sealy 1986). To counter this, the measurement of nitrogen isotopes should consider biological and environmental variations, as well as a thorough background study of baseline values for the area of study (Heaton 1999; Pate et al. 1998; Roberts et al. 2013; Sealy 1986).

Nitrogen isotope analysis is usually combined with carbon isotope analysis due to its effectiveness in distinguishing between marine and terrestrial based diets where there are both C₄ plants and marine foods in the diet, as C₄ plants have carbon isotopic values approaching those of marine organisms (Chisholm et al. 1982; Owen 2003; Schoeninger and Moore 1992; Schoeninger et al. 1983; Tauber 1981) (Figure 2.19).



Figure 2.19 Graph showing $\delta^{15}N_{(AIR)}$ and $\delta^{13}C_{(PDB)}$ values for European, American and South American sites. Adapted from multiple sources (see Roberts et al. 2013; Petruzzelli et al. 2012; Schoeninger 1995; Schoeninger and DeNiro 1984).

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This is one such example of how combining different isotopic analyses can clarify and contribute different kinds of information to research on prehistoric populations. Additional isotopic studies, such an oxygen isotope analysis, can also aid in answering questions about palaeomobility, adding another aspect of information.

Chemical Mobility Studies: Oxygen Isotope Analysis

Oxygen Isotopes

Oxygen exists as three stable isotopes (¹⁶O, ¹⁷O and ¹⁸O), which have natural abundances of 99.757‰, 0.038‰ and 0.205‰ respectively (Malainey 2010:43). Stable oxygen isotopes are incorporated into phosphate and carbonate in hydroxyapatite in tooth enamel and bone. Stable oxygen isotopes in body water equilibrate with δ^{18} O in hydroxyapatite at a constant body temperature of 37°C (see Bryant et al. 1996; lacumin et al. 1996; Longinelli 1984; Luz et al. 1984; Luz and Kolodny 1985). Oxygen isotope analysis involves comparisons between the two more abundant isotopes, ¹⁶O and ¹⁸O. This ratio is reported relative to a standard, which is SMOW for phosphate oxygen, or PDB for carbonate oxygen, in parts per thousand (‰) (Budd et al. 2004: 129; Price and Burton 2012). Oxygen isotope ratios (¹⁶O/¹⁸O) are related directly to body temperature, diet, drinking water composition and the relative proportions of oxygen in the atmosphere, after minor fractionation (see Kohn et al. 1996; Longinelli 1984).

Oxygen isotope abundances vary throughout the environment because of differences in climate and geography (Budd et al. 2004:128). The isotopic composition of meteoric water is linked to latitude, altitude, aridity, fluctuating rainfall and seasonal temperature change (Dansgaard 1964; Turner et al. 2009; White and Spence 1998). Variations in oxygen isotope abundances in the environment are due to the water cycle. Water that falls as precipitation is known as meteoric water and is depleted in ¹⁸O and enriched in ¹⁶O. This is because, during evaporation, the lighter isotope (¹⁶O) evaporates faster than the heavier

¹⁸O, resulting in a progressive loss of ¹⁶O values in latitude and an increase with temperature (see Dansgaard 1964; Knudson 2009; Turner et al. 2009). Conversely, during precipitation, the heavier isotope (¹⁸O) is lost as air masses move inland and up elevation, ensuring that ¹⁸O values in precipitation increase with a decrease in altitude and decrease further from the coast (see Dansgaard; Turner et al. 2009; White and Spence 1998).

As oxygen isotope ratios of meteoric water depend on several climatic and geographic factors, they are distinct for different geographic areas. When food sources (such as plants and animals) are isotopically related to local meteoric water, the isotopic composition of human tissues should correlate with that of the local water, allowing for distinctions between locals and foreigners in a burial population and thus, provenance studies (see Dansgaard 1964; Knudson 2009; Malainey 2010:44; Pate 2008b; White et al. 2000, 2002).

Oxygen isotope values in meteoric water and living organisms allow the study of human mobility through stable oxygen isotope analysis of human bone phosphate and carbonate (see Dansgaard 1964; Knudson 2009; Sanhueza and Falabella 2010; Turner et al. 2009; White 2000, 2002). Oxygen, reported as δ^{18} O (_{VPBD}) in palaeomobility studies, ranges from approximately –3.5‰ to –17.3‰, with more positive values found in lowland, coastal areas and more negative values found at inland higher altitude areas (see Moser et al. 1972; Sanhueza and Falabella 2010:128) (Figure 2.20). In addition, there have been numerous studies of surface, subsurface and meteoric water isotope values in Chile, which are summarised by Sánchez-Murillo et al. (2017).



Figure 2.20 Variation in $\delta^{18}O_{(SMOW)}$ of the average annual groundwater from precipitation from the coast to the cordillera, relative to the increase of altitude above sea level. Graph adapted from Moser et al. (1972) and Sanhueza and Falabella (2010).

Phosphate was formerly the more widely used method of recording δ^{18} O isotope ratios for human skeletal material (see Longinelli 1984; Luz and Kolodny 1989). However, further studies in carbonate have allowed for its inclusion in palaeomobility studies, as well as its potential use by cross-referencing it with phosphate results to check for post-mortem diagenetic alteration (see Bryant et al. 1996; Garvie-Lok et al. 2004; Gil et al. 2014; Iacumin et al. 1996; Turner et al. 2009).

Skeletal material, particularly fossilised specimens, have been found to be more susceptible to post-mortem diagenetic contamination than tooth enamel (see Hedges 2002; Iacumin et al. 1996; Lee-Thorp 2002; Lee-Thorp and Sponheimer 2003; Luz and Kolodny 1989; Nelson et al. 1986; Zazzo et al. 2004). However, there are many methods to identify the existence of post-mortem diagenetic alteration in bone (see Knudson et al. 2009; Lee-Thorp 2002; Lee-Thorp and

Sponheimer 2003; Zazzo et al. 2004). Therefore, current use of skeletal material for oxygen isotope analysis can be considered in light of these methods and their results.

Trace Elemental Analyses

Trace Elements

A trace element is a chemical element with a very low (trace) concentration of approximately 100 parts per million (ppm), or less, of the whole (Brown and Milton 2005:266). In biochemistry, a trace element is an element that occurs in very small amounts as an essential ingredient in a living organism, necessary for development, growth and overall health (Kleppinger 1984). Trace elements such as chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se) and zinc (Zn) are all incorporated into an organism's make up throughout its lifetime (Kleppinger 1984). Alkali-earth elements, such as magnesium (Mg), strontium (Sr) and barium (Ba) are incorporated into an individual's skeleton in significant amounts during a lifetime, while divalent metals, such as zinc, copper and iron are incorporated into the skeletal chemistry at lower (trace) levels (Castro et al. 2010; Kleppinger 1984; Reynard and Balter 2014).

In living organisms elements incorporated into apatite are separated into nonessential and essential elements. Non-essential elements are compared to that of essential elements with similar behaviour (e.g., Sr/Ca, Ba/Ca), to reconstruct trophic chains (see Burton and Price 1990; Peek and Clementz 2012). However, the process of biopurification can alter the amount of an element in the body relative to that of absorption.

Biopurification is the process within an organism whereby non-essential elements (such as Sr and Ba) are discriminated against in favour of essential elements (such as Ca). An example of this can be seen with strontium, barium and calcium ratios, where discrimination against the non-essential elements results in lower Sr/Ca and Ba/Ca ratios, meaning that the levels of these elements absorbed in bone are less than their levels in the diet, in proportion to the amount of Ca (see Burton and Price 1990; Burton et al. 1999; Elias et al. 1982; Reynard and Balter 2014). This process will repeat at each trophic level, as shown in Figure 2.21.



Figure 2.21 Theoretical food chain based on average Ba/Ca and Sr/Ca ratios as calculated by Balter (2004). Image courtesy of Peek and Clementz (2012:37).

Trace elements are present throughout the environment, including, but not limited to, soil, rocks, water, plants and animals (Reynard and Balter 2014:4). It is through these means that trace elements enter the bioapatite of the exogenous and endogenous skeleton of an individual during their lifetime and throughout the post mortem fossilisation process (see Arrhenius et al. 1957; Hodges et al. 1950; MacFadden et al. 2015; Parker and Toots 1970; Reynard and Balter 2014).

During the post-mortem fossilisation process, rare earth elements and high-field strength elements (such as uranium (U), thorium (Th) and hafnium (Hf)) which are not present while the organism is alive, are also incorporated into the skeletal
composition (see MacFadden et al. 2015; Reynard and Balter 2014). Rare earth elements (REEs) are a group of seven chemically similar metallic elements that were initially thought to be rare due to the rarity of the minerals from which they were originally isolated (Walters et al. 2011). In contrast, REEs are relatively plentiful in the Earth's crust, with cerium (Ce) being the most abundant (43 ppm) and thulium (Tm) being the least abundant (0.28 ppm) (Walters et al. 2011). Since REEs begin to be incorporated into human bone after death, they can give insight into diagenetic processes. Furthermore, elements such as thorium and uranium can also be used for dating, provided that they can be linked to diagenetic alteration soon after death (Millard and Hedges 1996; Pike and Hedges 2001; Reynard and Balter 2014:4). Thus, trace element analysis can contribute to information about biological (diet and metabolic) and environmental (mobility) signals, give insights into past soil and water compositions and be used for the dating of archaeological bones and teeth.

Trace Element Analysis and LA-ICP-MS

Over the past 50 years numerous techniques have been developed for the identification and quantification of trace elements in a variety of matrices (see Brown and Milton 2005; Malainey 2011; Pollard et al. 2007). Some of these techniques include X-ray fluorescence (see Bettinelli et al. 1992; Cox and Pollard 1977; Swanston et al. 2011), neutron activation analysis (NAA) (see Awadallah et al. 1986; Boullanger et al. 2015), atomic absorption spectroscopy (AAS) (see Hatcher et al. 1995; Hughes et al. 1976), high performance liquid chromatography (HPLC) (see Karapanagiotis et al. 2013; Wouters and Verhecken 1989) and thermal ionization mass spectrometry (TIMS) (see Li et al. 2006; Pollard et al. 2007:173). While these techniques have their own advantages and disadvantages (see Browns and Milton 2005; Malainey 2011; Pollard and Heron 1996; Pollard et al. 2007), for relevance to this research project this sub-section will focus primarily on the application of laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS).

LA-ICP-MS is an analytical technique used for determining elemental and (occasionally) isotopic concentrations from a range of substances (see Eggins et

al. 1998; Russo et al. 2002). LA-ICP-MS is relatively fast compared to other acid solution procedures, has excellent precision and sensitivity, and is minimally invasive, making it an ideal technique for use on archaeological materials (see Kennett et al. 2001; Neff 2012).

Laser Ablation (LA)

Laser ablation (LA) is the process where fine particles of material are removed from the sample surface of an object using a laser beam (see Eggins et al. 1998; Russo et al. 2002). The advantages of laser ablation, in comparison with acid digestion of samples for ICP-MS, are that it is minimally invasive (with most current equipment being able to ablate spots as small as $10-\mu m$ diameter) and requires only a very small amount of material (micrograms, versus milligrams for acid solution methods), therefore reducing the amount of analysis time and providing a spatial distribution for the results (Eggins et al. 1998; Neff 2012; Russo et al. 2002).

Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

In ICP-MS, material removed by laser ablation (or solution) are transported via argon gas into the plasma, which is maintained at between 5000 to 10,000 degrees by an external radio frequency current (Pollard and Heron 2008:29). The fine particles are then broken down into elements and ionised (Pollard et al. 2007:199). Following this, the ions enter a magnetic selector device and are separated based on their mass to charge ratios (Pollard et al. 2007:199). Finally, the ions are collected in a charge sensitive detector ready for analysis (Pollard et al. 2007:199). ICP-MS analysis can determine the majority of elements in the periodic table at concentrations below 1 parts per million (ppm), enabling an extremely sensitive analysis of the material (Pollard et al. 2007:61). ICP-MS also has the capacity to scan for all elements simultaneously, allowing for rapid sample processing (see Larson et al. 2005; Pollard et al. 2007:61).

ICP-MS has primarily been utilised in the medical (see Boaru et al. 2015; Goulle et al. 2014) and forensic (see Deconinck et al. 2006; Orrellana and Gálvez 2013; Watling et al. 1997) fields. However, ICP-MS has also been used in a range of other

areas, including but not limited to, climatic (see Baldini et al. 2002; Webster et al. 2007), geochemical (see Bourdon et al. 2003; Edwards et al. 2003; Pike and Hedges 2001) and archaeological research (See Kennett et al. 2001; Reynard and Balter 2014; Russo et al. 2002; Speakman and Neff 2005).

LA-ICP-MS on Skeletal Remains

Quantitative analysis of the trace elemental content in bones contributes information, which can be used to complement isotopic and archaeological studies (see Knudson and Price 2007). The elemental composition of human skeletal material has been used in archaeological research as it can provide additional data to human provenance studies (see Beard and Johnson 2000; Burton et al. 2003; Knudson and Price 2007) and the diets of individuals within a population (see Balter 2004; Burton and Price 1990; Castro et al. 2010; Reynard et al. 2011; Reynard et al. 2013; Safont et al. 1998). Furthermore, trace element analysis of skeletal material can also aid in examining the rate of diagenetic alteration in the skeletal material via measuring elements (such as uranium, iron, magnesium and aluminium) within the skeletal matrix and comparing them to exogenous elements within the surrounding soils (see Castro et al. 2010; Hodson et al. 2001; Reynard and Balter 2014).

Trace elemental analysis of human skeletal material is possible due to the biological uptake of some trace elements during human development (Kleppinger 1984). Trace element distribution in skeletal materials varies according to the structural and functional conditions of the bone (see Hill 1998; Parfitt 1983; Simmons and Grynaps 1989). Hydroxyapatite is the primary inorganic phase in bones and contains both minor and trace concentrations of elements used in skeletal growth (Castro et al. 2010:18; Klepinger 1984; Simmons and Grynaps 1989). At the structural level, bones are divided into either cortical or trabecular bone (Kleppinger 1984). Trabecular bones regenerate at a faster level than cortical bones, therefore the elemental composition of trabecular bones may provide more recent information about environmental exposure events than cortical bone (Castro et al. 2010:18; Hill 1998; Kleppinger 1984; Parfitt 1983; Simmons and Grynaps 1989). However, in archaeological studies, cortical bone is

the preferred material due to its dense structure and low susceptibility to postmortem diagenetic alteration (see Hedges 2002; Kleppinger 1984; Pate and Hutton 1988; Pate et al. 1999; Price et al. 1992).

Trace element analysis of human bone can contribute to information about the origin of skeletal material in approximately the last ten years of their life, since these elements are fixed in the human skeleton, providing information about nutritional uptake, exposure events and human provenance (Castro et al. 2010:18).

LA-ICP-MS in Archaeology

LA-ICP-MS has been used in archaeology since the mid 1990s and has significantly expanded the information that can be obtained from archaeological objects and hominin remains (see Neff 2012; Pollard and Heron 1996). LA-ICP-MS has been used on a variety of materials in archaeology, enabling information which was previously unobtainable through traditional archaeological methods.

Elemental analysis via LA-ICP-MS involves the examination of materials for a range of archaeological research, including, but not limited to, ceramic analysis (see Cochrane and Neff 2006; Li et al. 2006; Mallory-Greenough et al. 1998; Marengo et al. 2005; Neff 2003), glass analysis (see Barca et al. 2013; Conte et al. 2014; Shortland et al. 2007), metal analysis (see Dusssubieux et al. 2008; Hall et al. 1998; Longerich et al. 1987), paint and pigment analyses (see Arnold et al. 2007; Habicht-Mauche et al. 2000; Scadding et al. 2015), soil analysis (see Cook et al. 2006; Entwistle and Abrahams 1997; Entwistle et al. 1998), wood analysis (see Durand et al. 1999), tooth analysis (see Eggins et al. 2003; Simonetti et al. 2008) and analysis of bone (see Ghazi 1994; Knudson and Price 2007; Peek and Clementz 2012).

Sampling of these materials allows both qualitative and quantitative analyses of the material present, with qualitative analyses determining what elements are present, and quantitative analyses determining how much of each element is present (Castro et al. 2010). The determination of the different elements and how much of each element is present within the material has allowed archaeologists to understand what the material was made of and therefore, potentially, where it was originally made (see Castro et al. 2010; McLaughlin and Lednev 2012). Information about the origins of an object (provenance studies) can further aid in answering questions about human migration, trade and exchange, and social relations between prehistoric populations.

Trace Element Analysis in Archaeology: Case Studies

Trace element analysis research in archaeology has been used to distinguish between biogenetic and diagenetic signals in archaeological remains (see Pate et al. 1989; Price et al. 1992; Reynard and Balter 2014; Trueman et al. 2006). Pioneering studies in trace element analysis focussed on the importance of using trace elements to reconstruct and interpret dietary patterns (see Brown 1973; Gilbert 1975; Schoeninger 1979). However, since its establishment, it has been recognised that dietary reconstruction using trace elements depends on reliable biological signals, which can only be acquired through careful consideration of a range of biological, environmental and climatic factors (see Lambert et al. 1985; Reynard and Balter 2014).

The trace elemental study of strontium to calcium ratios (Sr/Ca) and barium to calcium ratios (Ba/Ca) has aided in answering questions about trophic level and marine versus terrestrial resource use by prehistoric populations (see Balter 2004; Burton and Price 1990; Burton et al. 2003; Knudson and Price 2007; Peek and Clementz 2012). This is because the relative concentrations of Sr/Ca and Ba/Ca in mammalian bioapatite are common biogeochemical indicators for dietary preferences in terrestrial food webs and between trophic levels (Peek and Clementz 2012:36).

Differentiation between marine and terrestrial environments through Ba/Sr ratios is possible as seawater has much lower Ba/Sr ratios than the Ba/Sr ratios found in terrestrial environments (see Burton and Price 1990). Consequently, marine organisms also have lower Ba/Sr ratios than terrestrial organisms. Low Ba/Sr ratios in marine organisms further generate correspondingly lower Ba/Sr

ratios in the bones of humans whose diet consists predominantly of marine resources (see Burton and Price 1990). Furthermore, these ratios are influenced by differences in the ratio of meat to plants in the diet of the individual, allowing an approximate differentiation of trophic level and dietary differences within an individual (Burton and Price 1990:552; Burton et al. 2003). However, due to variations in environmental, physiological and biogeochemical processes this is hard to establish accurately (see Balter 2004; Burton and Price 1990; Peek and Clementz 2012).

One study, which analysed variations in biological and environmental processes and their implications, is the research conducted by Peak and Clementz (2012) on Sr/Ca and Ba/Ca variations in biological and environmental sources. Peak and Clementz (2012) synthesised data from books, papers, reports and original data to assess the amount of biological and environmental variation in Sr/Ca and Ba/Ca ratios of marine and terrestrial ecosystems. A study of 149 marine mammals of 30 species and 83 prey items of 18 species found that there were substantial differences in the sources of variation between in both Sr/Ca and Ba/Ca ratios between terrestrial and marine environments (Peek and Clementz 2012:49). It was found that environmental sources account for most of the variations in Sr/Ca and Ba/Ca ratios in terrestrial systems. However, in marine systems, biological processes are primarily responsible for variations found in Sr/Ca and Ba/Ca ratios. Therefore, if environmental processes are invariant in marine ecosystems (seawater), then spatial or temporal differences may have little to no effect on Sr/Ca and Ba/Ca ratios of marine vertebrates, making Sr/Ca and Ba/Ca potentially useful global proxies for identification of trophic level and dietary preferences of marine vertebrates (Peek and Clementz 2012:36).

Trace Element Analysis and Diagenetic Alteration

As mentioned previously, the post-burial chemical alteration of bone presents problems for archaeologists when analysing the elemental composition of matrices (see Lambert et al. 1985). Due to this, substantial efforts have gone into recognising post-burial diagenesis and accounting for it in prehistoric materials (see Lambert et al. 1985; Pate and Brown 1985; Pate and Hutton 1988; Pate et al. 1989; Price et al. 1992; Radosevich 1993). Trace elemental analyses have been utilised in the recognition and interpretation of diagenetic alteration within skeletal matrices. Elements, such as rare earth elements (REEs) and high-field strength elements (Hf, U, Th), which are not present when an organism is alive, have been found to be incorporated post-mortem and can be used to understand the degree of post-burial diagenesis in skeletal materials (MacFadden et al. 2015; Reynard and Balter 2014:4).

REEs begin to be incorporated into the mineral lattices of skeletal elements upon death and can therefore provide excellent provenance indicators in fossil bone (see MacFadden et al. 2015; Trueman et al. 2004; Trueman et al. 2006; Tütken et al. 2008). After death, uptake of REEs continues for a least 10³ yr and following this was thought to become a closed system (see Trueman 1999; Patrick et al. 2002). However, recent research has found that individual REEs are incorporated at different rates and in different proportions, depending on the soil environment and bone type (see Hewartz et al. 2013; López-Costas et al. 2016).

Since REEs are incorporated into the skeletal matrix after death, REE patterns within a fossil may record changes in geochemical conditions during the fossilisation process (see Suarez et al. 2010). This is possible, as both REE and U/Th composition of fossil bones reflect associated pore water compositions during the period of bone recrystalisation (Trueman et al. 2006:4343). Changes in the skeletal matrix can then be used to interpret information regarding palaeoenvironmental conditions, taphonomic studies, and provenance studies (see Patrick et al. 2004; Trueman 1999; Trueman et al. 2005).

One example of REEs used in provenance studies of human skeletal remains, is a study conducted by Trueman et al. (2006). In this study, bones recovered from sediments at the Olorgesailie Formation of southern Kenya were used to test spatial and temporal questions based on discrimination analysis of REE, U and Th. Trueman et al. (2006:4343) found that location accounted for over 48% of the observed variation in the bone chemistry. Furthermore, it was established that bones recovered from eight discreet excavations within the same chronological

and stratigraphic layer, could be assigned to their location with over 70% accuracy (Trueman et al. 2006:4352). Finally, the bones recovered from four stratigraphic horizons (spanning approximately 0.5 million years) were assigned to their correct stratigraphic layer with over 90% accuracy (Trueman et al. 2006:4349). This study attests to the usefulness of REE, U and Th in providing excellent provenance indicators in fossil bone.

Trace elemental analysis has also been used in conjunction with isotopic analyses at archaeological sites, to better understand the extent of the diagenetic alteration in bone and enamel samples (see Knudson et al. 2012b; López-Costas et al. 2016). One example of this is research conducted by Knudson et al. (2012b) where trace elemental data was used to analyse two bone samples and one enamel sample as a proxy for diagenetic alteration in hydroxyapatite. Knudson et al. (2012b:443) found that the samples contained low U/Ca values, indicating little diagenetic alteration. Furthermore, it was found that while there were above normal (0–300ppm) values for Sr concentrations, suggesting possible biogenic and diagenetic Sr in skeletal matrices, there was not enough regional information on Sr to be sure it was due to diagenetic alteration, rather than higher geological Sr values for the area (Knudson et al. 2012b:443). This is one such study that provides an example of how trace element analysis can potentially be cross-referenced with isotope analysis to provide additional data.

Factors Affecting Isotope and Trace Element Analyses

Environmental Factors

In general, the isotopic and elemental composition of human tissues are closely related to that of the ingested foods and water in the environment (see Ambrose 1991; Beard and Johnson 2000; DeNiro and Epstein 1978; Owen 2003; Pate 1994, 2008; Schoeninger and DeNiro 1984; Sealy and van der Merwe 1986). However, variations in the climate and environment of an area have a direct impact on the isotopic and elemental concentrations in human tissues. Precipitation levels,

aridity, soil and plant variability and local water sources all influence the chemical composition of the human skeleton (see Heaton et al. 1986; Pate and Anson 2008; Pate and Owen 2014; Sealy 2006; Walker and DeNiro 1986).

Climatic Factors: The Influence of Precipitation and Aridity on Isotope and Elemental Analyses

Climatic influence plays an important role in the chemical composition of human tissues. For example, as explained earlier, vegetation in warmer versus cooler climates take on different carbon pathways (C₃ versus C₄) and can therefore be differentiated in human bone collagen (Ambrose 1991; Schoeninger and DeNiro 1984). Moreover, high δ^{15} N values (>14‰) are usually an indicator of the consumption of marine foods from upper trophic levels (Ambrose 1991; Ambrose and DeNiro 1986; Pate and Anson 2008). However, stable isotopic research conducted over the past 30 years in southern Africa (Heaton et al. 1986; Sealy et al. 1987), northern Africa (Schwarcz et al. 1999), eastern Africa (Ambrose and DeNiro 1986) and Australia (Anson 1997; Grocke et al. 1997; Pate et al. 1998; Pate and Anson 2008; Pate and Owen 2014) have identified a correlation between aridland habitats and enriched nitrogen levels (see Ambrose 1991; Ambrose and DeNiro 1986; Heaton et al. 1986; Pate and Anson 2008; Sealy et al 1987). Elevated bone collagen δ^{15} N levels have been found in animals living in areas receiving less than 400 mm of rain annually (Anson 1997; Heaton et al 1986; Ambrose and DeNiro 1986).

Two proposed mechanisms have been put forward to explain the $\delta^{15}N$ enrichment in the bone collagen of animals living in arid habitats. The first is that there is $\delta^{15}N$ enrichment in the soils and plants of arid land habitats, which are being passed up the food chain through their consumers (see Heaton 1987; Schwarcz et al. 1999; Shearer and Kohl 1986). The second explanation is that animals living in arid land habitats undergo physiological adaptations due to water/nutritional stress, which results in $\delta^{15}N$ enriched tissues (see Ambrose and DeNiro 1986b, 1987; Bada et al. 1989; Cormie and Schwarcz 1996; Hobson et al. 1993; Schoeninger et al. 1997; Steele and Daniel 1978). However, studies conducted in the Atacama Desert of northern Chile, (which receives less than 1 mm of rain annually), have found conflicting evidence, as baseline faunal values for animals from this habitat have retained δ^{15} N values within the normal range (see Petruzzelli et al. 2012; Roberts et al. 2013; Tykot et al. 2009). Further research into this area in the Atacama Desert may reveal more data and therefore answers to why this phenomenon does not seem to have affected these arid land animals in the same way.

Additionally, differences in δ^{18} O values are related to variations in relative humidity. Isotope values of precipitation change systematically with altitude and latitude resulting in distinct oxygen isotope ratios for water derived from different geographic regions (Pate 2008b:180). Climate change can alter the oxygen composition of precipitation, and therefore result in changes in relative humidity, which in turn results in oxygen isotope variations in human skeletal tissues (Anson 1997; Grocke 1997; Owen 2003; Pate 2008b; Roberts et al. 1999). Consequently, research into geographic locality using the oxygen isotope composition in skeletal tissues should be conducted on skeletons within the same chronological/climatic period, as differing time periods will likely have different climatic conditions, influencing the δ^{18} O composition of human tissues (Budd et al. 2004; Pate 2008b).

Environmental Influences on Isotope and Elemental Analyses: Soils and Plants

Soil composition and plant types also have a significant influence on isotopic and elemental concentrations in a consumers' tissues (see Beard and Johnson 2000; Pate 1994). Isotopic differences at the base of food chains are passed up to higher level consumers. For example, variations in the isotopic composition of soils are taken up by plants and, in turn, animals and humans. Baseline studies of soils, flora and fauna in the area specific to the study allow inferences about the relative use or marine versus terrestrial foods, C₃ versus C₄ foods and the adoption of agricultural practices (see O'Leary 1988; Pate and Noble 2000). Geographic variability (e.g., coastal versus inland and valley versus highlands) plays a major role in isotopic variability and allows consumers to be traced back to the environments they came from. In order to do this, baseline studies need to be conducted for the region of study over a long period of time to ensure that

seasonal variability and environmental changes are accounted for (see Barker 1987; Dawson 1995; Dawson and Ellis 1994; Dawson and Hulbert 1970; Ellis et al. 1997; Owen 2003; Pate 2008a; Tykot et al 2009).

Trophic Level and Fractionation

Originally it was thought that the chemical composition of bones was a direct reflection of the foods the individual had consumed (van der Merwe and Vogel 1978). However, research into the chemical structure of human skeletal material has proved that the relationship between the isotopic composition of consumers and their diet needs to incorporate adjustments for isotopic fractionation (Ambrose and Norr 1993; Emerson 2005; Harrison and Katzenberg 2003; Kellner & Schoeninger 2007; Kosiba et al. 2007; Passey et al. 2005; Prowse et al. 2004; Tieszen and Fagre 1993; van der Merwe and Vogel 1978).

Fractionation is the chemical enrichment or depletion that occurs due to metabolic selection or discrimination against one isotope over another during the process of collagen or apatite formation (Ambrose and Norr 1993). Fractionation is governed by the position of the consumer in the food chain (trophic level), meaning those that are higher up the food chain have more positive delta (δ) values than those lower on the food chain (Ambrose and Norr 1993; Bryant and Froelich 1995; Dufour et al. 1999; Pate 1994; Schoeninger and DeNiro 1984; Schoeninger et al. 1993).

Field research and experimental studies (see Ambrose and Norr 1993; DeNiro and Epstein 1978; Jim et al. 2006; Sealy and van der Merwe 1986) have found that the shift up the food chain for stable carbon isotopes, between herbivore and carnivore collagen, is approximately +2%, while that between herbivore meat and carnivore collagen is approximately +5%. However, further studies have found that the offset between diet and bone collagen values between C₃ protein and C₄ non-protein diets is approximately 2.0%–2.3% (Ambrose and Norr 1993). Additionally, when comparing C₄ protein and C₃ non-protein diets, the offset between diet and bone collagen increases to 9.6%–10.2%, which produces a discrepancy in the amount of C₄ by as much as 45% (Ambrose and Norr 1993). As maize is one of the leading C₄ plants found in most archaeological deposits, and

since maize has approximately 10% protein, this would lead to the underrepresentation of maize in bone collagen (Ambrose and Norr 1993).

As mentioned previously, studies have demonstrated that the overall range for stable carbon diet-bone apatite isotope values sit between 8‰ and 14‰ (see Ambrose and Norr 1993; Emerson 2005; Harrison and Katzenberg 2003; Kellner & Schoeninger 2007; Kosiba et al. 2007; Passey et al. 2005; Prowse et al. 2004; Tieszen and Fagre 1993). Furthermore, it has been recognised that carbon can be read for diet based on two models: the linear mixing model and the macronutrient routing model (Chrisholm et al. 1982; Krueger and Sullivan 1984). The linear mixing model, which is primarily applied to apatite carbon, is based on the premise that all the carbon atoms from dietary proteins, carbohydrates and lipids are incorporated into the animal tissue in the same way (Chrisholm et al. 1982; Krueger and Sullivan 1984; Tykot et al. 2009:160). In contrast, the macronutrient model recognises that protein in the diet is selectively incorporated into the tissue, making consumers' collagen a good indicator of dietary protein, carbohydrates and lipids (Ambrose and Norr 1993; Krueger and Sullivan 1984; Tieszen and Fagre 1993). Consequently, using both carbon collagen and apatite together in stable carbon isotope analysis aids in a better interpretation of the carbon component of diets (Tykot et al. 2009:160).

In contrast to terrestrial food chains, marine food chains are longer with more $\delta^{15}N$ enrichment steps (Ambrose et al. 1997; Minagawa and Wada 1984; Pate and Anson 2008; Schoeninger and DeNiro 1984; Schoeninger et al. 1997). Fractionation in ${}^{15}N/{}^{14}N$ ratios demonstrates that the $\delta^{15}N$ values are approximately 3–4‰ more positive than the food they eat (Fry 1988; Minagawa and Wada 1984; Schoeninger and DeNiro 1984; Schoeninger et al. 1983). Moreover, marine $\delta^{15}N$ values tend to be higher than those of terrestrial consumers due to the differential distribution of nitrification and denitrification on land and in the sea (Pate 1994; Tieszen and Chapman 1992; Tieszen and Fagre 1993; Sealy 2006:574). Additionally, as marine plants and marine herbivores are minor components in the diets of terrestrial animals, bone collagen $\delta^{15}N$ values can provide a means to distinguish between diets based on marine foods versus diets based on terrestrial foods (Schoeninger and DeNiro 1984; Tieszen and

Chapman 1992).

Finally, stable oxygen isotopes in the carbonate portion of hydroxyapatite (Ca_{10} (CO_3)₆ (OH_2)) of bone reflect the isotopic composition of body water at 37 degrees Celsius (Dansgaard 1964; Lightfoot and O'Connell 2016; Longinelli 1984; Luz et al. 1984). Body water $\delta^{18}O$ in consumers is further influenced by the oxygen isotopic composition of drinking water and, to a lesser extent, oxygen in air and food sources (Dansgaard 1964; Longinelli 1984; Luz and Kolodny 1989; Luz et al. 1984). Fractionation of oxygen isotopes occurring between trophic levels is similar within and between species, with only minor deviation for different metabolic processes and habitats between animals (Budd et al. 2004; Levinson et al. 1987; Longinelli and Nuti 1973; Longinelli 1984; Luz et al. 1984; Sponheimer and Lee-Thorp 1999; White et al. 2004; Turner et al. 2009).

Human Skeletal Material

In an adult skeleton, teeth provide a record of childhood diet and residence (see Hillson 1996, 2000; Smith 1991), whereas the chemical structure of bone represents the long-term adult dietary composition and environment of residence of the individual in the last decades years of their life (Hedges et al. 2007; Parfitt 1983; Pate 1994, 2008; Sealy et al. 1995; Stenhouse and Baxter 1979; White and Folkens 2005). This is due to bone turnover, known as modelling during skeletal development, and remodelling after the age of approximately 20 years and until death (Pate 1994; Sealy et al. 1995). Bone remodelling ensures that the chemical composition of bone collagen continues to change throughout an individual's lifetime, meaning that the chemical composition of an individual's bone collagen is different at birth than at death (Larsen 1987; Pate 1994).

Whole cortical bone is composed of approximately 70% organic (collagen), 20% inorganic (hydroxyapatite), 8% water and 2% non-collagenous material (Klepinger 1984:75). The collagen portion of the bone is formed primarily from ingested protein, while carbonate is deposited from dissolved bicarbonate, which is drawn from all dietary components (Ambrose and Norr 1993; Krueger and Sullivan 1984; Tieszen and Fagre 1993).

Elements and amino acids from ingested food and water are incorporated into the organic collagen and inorganic hydroxyapatite components of bone, allowing for comparison against baseline data and inferences about dietary composition and landscape use (Katzenberg and Harrison 1997; Pate 1994; Sandford and Weave 2000; Schoeninger 1995; Schoeninger and Moore 1992; Schwarcz and Schoeninger 1991).

Hydroxyapatite is the primary inorganic phase in bones and contains both minor and trace concentrations of elements used in skeletal growth (Castro et al. 2010:18; Klepinger 1984; Simmons and Grynaps 1989). At the structural level, bones are divided into either cortical or trabecular bone (Kleppinger 1984). Trabecular bones regenerate at a faster level than cortical bones, therefore the elemental composition of trabecular bones may provide more recent information about environmental exposure events than cortical bone (Castro et al. 2010:18; Hill 1998; Kleppinger 1984; Parfitt 1983; Simmons and Grynaps 1989). However, due to the biological composition of bone, the organic portion of bone begins to degrade after death, leading to a process known as post-mortem diagenesis (Collins et al. 2002; Hedges 2002; Henderson et al. 1983; Pate and Hutton 1988; Price et al. 1992).

Post-Mortem Diagenetic Alteration (Diagenesis)

'The key to successful retrieval of biomolecular information is an understanding of the mechanisms of biomolecular deterioration...' (Collins et al. 2002:384).

The chemical composition of buried bones is the result of both pre-mortem (during life) and post-mortem (after death) changes to the bone after the burial took place (López-Costas et al. 2016:43). Post-mortem diagenetic alteration (diagenesis) is the process whereby the chemical composition of skeletal matrices is altered by exposure to taphonomic processes and the burial environment (see Collins et al. 2002; Hedges 2002; López-Costas et al. 2016; Price et al. 2002). Accurate interpretations from the elemental composition of human bone recovered from archaeological sites depends on an understanding of post-mortem

diagenetic alteration of the material (see Nelson et al. 1986; Pate et al. 1989:303). This is because *in vivo* chemical signatures in bone can be obscured by postmortem changes in the soil environment (Pate et al. 1989:303). However, an understanding of diagenetic changes can be difficult due to variations in skeletal matter and environmental surroundings (see Hedges 2002; Willmes et al. 2016:103).

During life, bone composition changes by incorporating and releasing elements derived from food and drink, and through environmental exposure (see DeNiro and Epstein 1978; López-Costas et al. 2016; Schwarcz 1991). This constant turnover of elements continues until the individual dies (see Klepinger 1984; Nelson et al. 1986; Price et al. 1992). After death, bacterial action stimulates postmortem chemical alterations, which further change the bone composition of the individual (López-Costas et al. 2016:44; Pfretzschner 2006). Once the individual is buried, the chemical composition of the skeleton continues to change through direct contact with ground waters and soils from the local area (see Hedges et al. 1995; López-Costas et al. 2016; Maurer et al. 2014; Nielsen-Marsh et al. 2007; Nielsen-Marsh and Hedges 2000; Pfretzschner 2006; Price et al. 1992).

Research over the last 50 years has made significant contributions to our understanding of the processes that occur during post-mortem diagenetic alteration (see Henderson et al. 1983; Kocsis et al. 2010; López-Costas et al. 2016; Nelson et al. 1986; Pate et al. 1989; Price et al. 1992). Mapping of elemental distributions, through elemental and isotopic analyses, has been used to interpret the degree of diagenetic alteration in skeletal matrices (see Fernandes et al. 2013; Jacques et al. 2008; Koenig et al. 2009; Kohn et al. 1999; López-Costas et al. 2016; McCormack et al. 2015; Trueman et al. 2008). Systematic mapping of high strength field elements (such as U, Th and Hf) and rare earth elements (REEs) has provided an enhanced understanding of chemical processes and allowed for the identification of diagenetic alteration in skeletal materials (Willmes et al. 2016:103). Mapping of these elements is done on the principle that organisms contain no REEs, U and Th. Therefore, a higher presence of them in archaeological bone suggests that they have been absorbed from the surrounding burial soils after death (see Boel 2011; Budd et al. 2000; Eggins et al. 2003; Grun et al. 2008; Hinz and Kohn 2010; Koenig et al. 2009).

Furthermore, research into post-mortem diagenetic alteration has also contributed information about the burial characteristics of a grave (see Müller et al. 2011; Salesse et al. 2014), the taphonomic history of bones (see Bocherens et al. 2008; Maurer et al. 2014) the burial location and disturbance (see Gonzalez-Rodríguez and Fowler 2013; Reynard and Balter 2014; Trueman et al. 2006) and discrimination of pre-mortem and post-mortem signals in archaeological bone to determine diet and mobility (see Bentley 2006; Knudson and Price 2007; Lambert et al. 1985; Nelson et al. 1986; Price et al. 1992).

Finally, it is important to note that, despite the research already conducted on the mechanisms of post-burial diagenetic alteration, diagenetic processes are complex and involve many chemical, mechanical, physical and histological changes at different scales, making them difficult to accurately interpret on a general basis (Hedges 2002; López-Costas et al. 2016:44; Stathopoulou et al. 2008).

Stable Carbon and Nitrogen Isotope Analysis: Global Case Studies

Overview

Stable carbon and nitrogen isotope analyses of human remains have been used to broadly examine the diet and dietary components of prehistoric humans. Globally, stable carbon and nitrogen isotope analyses have been used to investigate issues concerning marine versus terrestrial diets (see DeNiro and Epstein 1978, 1981; Falabella et al. 2007; Schoeninger and DeNiro 1984; Sealy and van der Merwe 1986; 1988; Tauber 1981; Vogel and van der Merwe 1977; Walker and DeNiro 1986), the differential consumption between C₃ and C₄ plant resources, which can aid in answering questions about hunter-gatherer versus maize-related agricultural dietary choices (see Falabella et al. 2007; Falabella et al. 2008; Hedges and Reynard 2007; Koch 2007; Sanhueza and Falabella 2010), and the differing amounts of resource consumption, which can lead to information on human behaviours relating to social status, sex and age, as well as geographic locality. Stable carbon and nitrogen isotope values can also be compared to baseline human and faunal values and used to investigate geographical provenance (see Pate et al. 2002; Schoeninger and DeNiro 1984).

This section of the literature review examines these theories on a global level, placing this research project in a world context, with reference to stable carbon and nitrogen isotopic applications and case studies supporting these applications. From this, the kind of research questions that can be answered using stable carbon and nitrogen isotope analysis will be illustrated, starting with case studies from Europe, Australia, North America and Central America.

Europe

Stable carbon and nitrogen isotope analyses conducted in Europe have been predominantly used to examine dietary change from the Mesolithic (c. 12,000–5000 BP) to the Neolithic (c. 5000–1000 BP). In Europe, stable carbon and nitrogen isotopic evidence in the Mesolithic Period shows diets primarily based on hunting and gathering practices with a high reliance on marine protein (see Liden 1995; Lubell et al. 1994; Schulting 2005; Schulting 2011; Schulting and Richards 2001, 2002a, 2002b; Tauber 1981, 1983, 1986).

During the Mesolithic-Neolithic transition, a range of sites in Europe revealed a shift from isotopic values indicating a high reliance on marine resources, to isotopic values showing strongly terrestrial signals (see Fischer et al. 2007; Liden 1995; Lubell et al. 1994; Price et al. 2007; Richards et al. 2003; Schulting 2011; Tauber 1981, 1986). Furthermore, sites such as Port Blanc in the northwest of France and the site of Er Yoh (located on a small islet off the Morbihan coast in France), show a shift from a reliance on marine protein in the Mesolithic, to the consumption of terrestrial C₃ resources, with the addition of marine foods, during the Neolithic (see Schulting 2005; Schulting et al. 2004).

Additionally, a more rapid shift away from marine resources across the Mesolithic-Neolithic, at a range of sites across England (see Shulting 2008; Tresset 2003), Ireland (see Sheridan et al. 2008) and Spain (see Lubell et al. 1994), demonstrates a transition from marine to terrestrial resource use during the Neolithic (Schulting 2011:27). Furthermore, several sites in the Mediterranean have demonstrated stable carbon and nitrogen isotopic values indicating no evidence for the consumption of marine resources (see Lange-Badré and Le Mort 1998; Papathanasiou 2003).

One study where stable carbon and nitrogen isotope analysis reveal no isotopic evidence for the consumption of marine resources is a study conducted by Papathanasiou (2003, 2011) at six Neolithic Greek sites. Stable carbon and nitrogen isotopic ratios were taken from the bone collagen of 101 skeletal samples from the sites of Alepotrypa, Franchthi, Kephala, Theopetra, Tharrounia and Kouveleiki in Greece (Figure 2.22).



Figure 2.22 Neolithic Greek sites referred to in text. Map adapted from Papathanasiou (2003).

Stable carbon and nitrogen isotope results indicated a diet consisting primarily of C₃ terrestrial foods, with very little contribution of marine protein in the individuals analysed (Papathanasiou 2011:91). These results support the hypothesis that, regardless of geographic location (coastal or otherwise), Neolithic Greece was occupied by groups focussed on terrestrial resource use, with only occasional use of near-shore marine resources (Papathanasiou 2011:91). Papathanasiou's (2011) study indicates the usefulness of isotopic studies to cross-check theories about marine resource use, as although several of these populations living on the coasts of Greece, isotope values indicate that they were not exploiting marine resources during this period of time.

Conversely, stable carbon and nitrogen isotopic values at sites, such as Pendimoun in southern France (see Le Bras-Goude et al. 2006) and Samari in Italy (see Giorgi et al. 2005), among others, show a continuity of diet throughout the Mesolithic to Neolithic transition, with populations continuing to consume marine resources into the Neolithic (see Eriksson 2004; Richards et al. 2001; Rose 1995). This is one such example that demonstrates that, although there does seem to be a general trend showing the move towards the consumption of C_3 based terrestrial resources in Europe, it is not homogenous throughout Europe, with variations in timing and resource use.

Australia

Stable carbon and nitrogen isotope studies in Australia have been used to explore a number of issues, such as coastal and interior dietary composition (see Collier and Hobson 1987; Pate 1995a, 1995b, 2000, 2002; Pate and Schoeninger 1993), seasonality and territoriality (see Pate 2000; Pate and Owen 2014), palaeoclimatic research (see Anson 1997; Austin and Sala 1999; Cook 2001; Pate and Anson 2008; Roberts et al. 1999), and C₃ versus C₄ resource consumption (see Pate and Noble 2000).

One example of how stable carbon and nitrogen isotope analyses have been used for research in Australia, is a study conducted by Pate et al. (2002) on unprovenanced skeletal material from the South Australian Museum. Pate et al. (2002) used bone collagen stable carbon and nitrogen isotope analyses to determine the general geographic origins of 91 individuals collected in South Australia during the 19th and 20th centuries (Pate et al. 2002:1).

Prehistoric individuals from various known localities within four distinct environmental zones were used as baseline data for each zone to compare to the isotopic values of the unprovenanced individuals (Pate et al. 2002:1). The prehistoric control group consisted of three individuals from the coastal Coorong, 12 individuals from the coastal Murray Mouth and Lake Alexandra, 110 individuals from the Lower Murray River site of Swanport and 32 individuals from the Roonka site near Blanchetown on the Upper Murray River (see Pate 1997; Pate 1998a, Pate 1998b; Pate et al. 2002:2; Pate and Schoeninger 1993) (Figure 2.23).



Figure 2.23 Image showing the locations of known individuals from the prehistoric control group in Pate et al.'s (2002) study. Map adapted from Pate et al. (2002).

Results of this study indicated that 77 out of the 91 individuals could be reliably assigned to particular geographic regions based on their stable carbon and nitrogen isotope values (Pate et al. 2002:2). Overall, 24 of the unprovenanced individuals exhibited stable carbon and nitrogen isotope values that aligned with previous known values for individuals from the Coorong area. Additionally, 27 individuals showed values from the Murray Mouth, 26 from the Swanport site at the Lower Murray River, and nine individuals showed intermittent values between the Swanport and Roonka zones (Pate et al. 2002:2). Out of the 91 samples only two samples exhibited values that did not correlate with any of the current known human standards (Pate et al. 2002:2). This study is one example of an Australian isotopic study which demonstrates one of the uses of employing stable carbon and nitrogen isotope analyses to determine the geographic origins of a burial population.

North America

Stable carbon and nitrogen isotope analyses in North America have explored issues such as marine versus terrestrial resource use (see Bourque and Krueger 1994; Hutchinson and Norr 1994; Little and Schoeninger 1995) and the relative consumption of C₃ versus C₄ (maize) resources temporally (see Boutton et al. 1991; Buikstra et al. 1988; Boyd et al. 2008; Larsen et al. 1992; Schoeninger et al. 1997; Vogel and van der Merwe 1977) and spatially (see Buikstra and Milner 1991; Boyd et al. 2008; Katzenberg et al. 1995; Walker and DeNiro 1986). Additionally, both old and new studies have examined the adoption of maize-based agricultural practices across the country and the geographic, political and economic factors that may have influenced dietary practices (see Katzenberg et al. 1995; Rose 2008).

One of the first cases in Canada that illustrated the usefulness of isotope studies to address questions concerning the integration of cultivated plants into huntergatherer diets and the adoption of agricultural practices, was conducted by Schwarcz et al. (1985). This study isotopically examined the carbon and nitrogen content of human skeletal remains from nine geographically distinct archaeological sites, representing 13 occupations, in southern Ontario (Figure 2.24). The dates for these populations ranged from c. 4250–314 BP, with the earlier sites being occupied by hunter-gatherers and the later sites having evidence of cultivation of native plants, as well as cultivation of imported food, e.g., maize, beans and squash (Schwarcz et al. 1985:191). At these sites, there was archaeological evidence indicating the introduction of maize to southern Ontario around 1250 BP and the introduction of beans around 850 BP (Yarnell 1976). The skeletal remains were analysed to examine the mean carbon isotopic composition of the diet of the indigenous population and see whether there was a shift in the in the δ^{13} C values of their diets after the introduction of maize (Schwarcz et al. 1985:188).



Figure 2.24 Map of Canadian archaeological sites referred to in text. Map adapted from Schwarcz et al. (1985).

Additionally, the diets of these populations were examined to observe whether the introduction of beans, found in the archaeological evidence, affected their diets causing a decrease in the δ^{15} N content of human bone collagen, as legumes are deficient in nitrogen, compared to meat and fish. The results from this study Bianca Waldie 100

indicated that the pre-agricultural peoples at these sites consumed predominantly C_3 plants and animals that were consuming C_3 plants. It was also noted that between c. 1550 and 950 BP there was a notable increase in the C_4 content of the human diets coinciding with the gradual introduction of maize. However, there was no significant change in the nitrogen levels of the human bone collagen at these sites. Consequently, although beans were introduced around 850 BP they did not figure prominently as a protein source in the populations' diets, with meat and fish still being the main sources of protein even after the advent to agriculture in this region (Schwarcz et al. 1985:203). This study demonstrates the potential utility of employing stable carbon and nitrogen isotope analyses to answer questions about the introduction of maize-based agriculture.

Another North American study that investigated intra-community variation in diet during the adoption of maize-based agricultural practices, was conducted by Rose (2008). Rose (2008:413) investigated the transition to maize-based agricultural practices in a region where farming systems were already developed locally from indigenous plants. Stable carbon and nitrogen isotope analyses of the bone collagen was examined for individuals from seven archaeological sites in west-central Illinois (Rose 2008:414) (Figure 2.25).



Figure 2.25 Map of Illinois, illustrating the locations of sites relevant to the case study. Map adapted from Rose (2008).

Results indicated that maize was not eaten in large quantities in the Middle Woodland Period (c. 2100–1700 BP), but gradually increased through the Late Woodland Period (c. 1550–950 BP), and the Mississippian era (c. 950–300 BP) (Rose 2008:434). Additionally, isotopic results indicated variability in maize consumption within the communities, with some individuals consuming no maize, while others consumed high proportions of maize. Rose (2008:434) found that sex, status and age did not explain the intracommunity variability in maize-consumption. However, stable nitrogen isotope ratios demonstrated sex differences, with males generally having higher nitrogen ratios than females, possibly due to dietary and physiological differences (Rose 2008:434). This is one study where stable carbon and nitrogen isotope analysis can illustrate intracommunity variation in diet and resource use.

Central America

Stable carbon and nitrogen isotope analysis in Central America have been used to explore a range of issues concerning diet and landscape use. Studies pertaining to the adoption of maize-based agriculture (see DeNiro and Epstein 1981; Farnsworth et al. 1985; Norr 1991; White et al. 1993; White et al. 1994; Williams et al. 2017), geographic patterning of diet (see Gerry and Krueger 1997), gendered food behaviour (see Reed 1994; White 2005; White et al. 1993), and the relationship between diet and status (see Gerry and Krueger 1997; White 1994; White and Wright 1996) have all been explored throughout the region. Additionally, the ancient Maya of Central America are one of the most extensively isotopically investigated ancient civilisations in the world (Somerville et al. 2012:1540).

One Central American example of the use of stable carbon and nitrogen isotope analysis is at the site of Lamanai in Belize (Figure 2.26). Isotope analysis was conducted on 51 human skeletal samples at Lamanai, ranging from the pre-Classic (c. 3200–1700 BP), through the Late and Terminal Classic (c. 1350–950 BP), up to the post-Classic and Historical Periods (c. 950–330 BP).



Figure 2.26 Map showing the location of Lamanai in Central America. Map adapted from Somerville et al. (2012) and White and Schwarcz (1989).

Results indicated that there was a variable emphasis on maize, with pre-Classic populations showing a strong reliance on maize, constituting approximately 50% of the whole diet. Maize consumption then decreased through the Late Terminal and Classic periods, with consumption around 37% of the total diet. Finally, maize consumption rises significantly in the post-Classic and Historical periods, constituting approximately 70% of the total diet (White and Schwarcz 1989:451). When cross-referenced with archaeological data (such as grave goods), it was found that high status individuals were consuming less maize than low status individuals at Lamanai (White and Schwarcz 1989:468).). This dietary variability was likely the result of political and economic activities, with high status people

having access to more protein and a wider range of food than lower status individuals.

Additionally, Somerville et al. (2012) compiled a database of carbon and nitrogen isotope values for 102 individuals from Maya populations of the southern lowlands during Classic Period (c. 1750–950 BP). Using two isotopic modelling techniques, a simple carbon isotope model (see Froehle et al. 2010; Kellner and Schoeninger 2007) and a multivariate isotope model (see Froehle et al. 2012), Somerville et al. (2012) found that the elite Maya demonstrated significant temporal variability within their dietary patterns, whereas the commoners' diets remained relatively stable over time (Somerville et al. 2012:1551). Somerville et al. (2012:1551) suggest that this is likely due to the possibility that elite subsistence strategies were more closely linked with political and economic circumstances, while commoners' subsistence strategies remained the same over time. This is one example where social, political and economic differences can be seen through both archaeological (material remains) and chemical (isotopic) data.

Regional Applications of Stable Carbon and Nitrogen Isotope Analysis

Stable carbon and nitrogen isotope analysis in South America has focussed primarily on human diet and resource use during the Holocene, examining issues such as marine versus terrestrial resource use (see Aufderheide and Santoro 1999; Petruzzelli et al. 2012; Santana-Sagredo et al. 2015; Santana-Sagredo et al. 2016), C₃ versus C₄ resource use and the adoption of agricultural practices (see Gil et al. 2014; Roberts et al. 2013). Additionally, stable carbon and nitrogen isotope studies have also been able to answer questions about social status within a society (see Hastorf 1985; Ubelaker et al. 1995). Keeping in mind that there are significant differences in the environmental, climate and ecological regimes in these areas, case studies in the countries of Ecuador, Argentina, Peru and northern Chile, referred to in this section were chosen in order to highlight research questions that have been focussed on in the region, and are by no means exhaustive (Figure 2.27).



Figure 2.27 Map of archaeological sites relevant to regional applications of stable carbon and nitrogen isotope analysis in South America.

Ecuador

One archaeological site where stable carbon and nitrogen isotope analysis was used to make inferences about status and society was the site of La Florida, in the Quito neighbourhood of Ecuador. An isotopic study conducted by Ubelaker et al. (1995) on 32 individuals from the Chaupicruz Phase (c. 1850–1500 BP) found that there were differences in δ^{13} C values between high and low status individuals.

Archaeological evidence, in the form of grave goods, was used to determine the status of the individuals analysed (Ubelaker et al. 1995:405). Stable isotopic results indicated that high status individuals have less negative δ^{13} C values than low status individuals (Ubelaker et al. 1995:405). Archaeological and ethnological analyses led to the hypothesise that there was a greater consumption of maize

beer by adult males within the populations (Ubelaker et al. 1995:407). This is one such example of where stable carbon and nitrogen isotope analysis has been used to make inferences about social status within a population.

Argentina

One example of where stable carbon and nitrogen isotope analysis was used to investigate subsistence patterns was a study conducted by Gil et al. (2014) in central-western Argentina. Gil et al. (2014:215) looked at changes in stable isotope data through time by looking at temporal trends in the collagen δ^{13} C and δ^{15} N and hydroxyapatite δ^{13} C of 131 individuals from 37 archaeological sites in the region (Figure 2.28).



Figure 2.28 Map showing the locations of the archaeological sites in Argentina as referred to in the text. Map adapted from Gil et al. (2014).

Stable carbon and nitrogen isotope results from this study challenged the previous notion that human subsistence over the past 2500 years BP was homogenous and rich in maize, especially during the Inka cultural period (see Falabella et al. 2007; Gil et al. 2014:224).

Results indicated that there was great variability in the diets of the individuals in central-western Argentina, showing three periods of differential C_4 (maize) intake

over the last 2500 years. Gil et al. (2014:224) further cross-referenced the isotopic data with palaeoclimatic data for the region (see von Guten et al. 2009) and found that the gradual increase in maize intake from 2550–1150 BP coincides with a warmer period and introduction to maize in the area (Gil et al. 2014:224; von Guten et al. 2009). Following this, was a fluctuating period of high maize intake over approximately 600 years, followed by a decline in maize intake around 500 BP, which coincided with a marked decrease in temperature in the region around 550 BP (Gil et al. 2014:224; von Guten et al. 2009).

Gil et al. (2014:224) suggested that warmer climatic conditions (between c. 800 and 580 BP) provided favourable conditions for the cultivation of maize, and the onset of cooler conditions (after c. 550 BP) prompted changes in human diet in central western Argentina. Additionally, the isotopic data in this study suggest that the most significant increase in maize consumption was before Inka occupation, which coincides with a similar trend found in central Chile (see Falabella et al. 2007).

Peru

Another example of isotope analysis being used as an indicator of social change and inequality of class and sex within a group is an isotopic study conducted on 50 individuals from the early Intermediate/Middle Horizon Period (c. 2150–950 BP), Wanka I (c. 950–650 BP), Wanka II (c. 650–480 BP) and Wanka III (c. 480– 418 BP) phases in Peru. Hastorf (1985:19) theorised that the elite in the Upper Mantaro Valley Region of the central Peruvian Andes would have been consuming more maize than the non-elite. However, when the isotope ratios were examined, initially no marked difference was found in the values between commoner and elite populations. In spite of this, after looking at the individual values of both of the sexes it was found that women consumed much less maize than men. From this new evidence Hastorf (1985:21) came to the conclusion that differential consumption of maize by males suggests that they either had increased access to maize within the home or that they were consuming it outside the household in ritual feasting ceremonies (Hastorf 1985:21). Thus, social differentiation was inferred through the diet of the population using isotope analyses. Although, the males may not have been consuming more maize in "ritual feasting ceremonies" but rather may have just been consuming more of it while they were out in the field harvesting it. This is another interesting aspect of isotope analysis that has been used to develop a different level of information regarding not only the economy of the people but also aiding in reconstructing details of their cultural practices. By looking at this study it is evident that more than just the types of food eaten can be identified. This study demonstrates the types of cultural questions that can be answered using stable carbon and nitrogen isotope analysis.

Northern Chile

One northern Chilean site, which involved stable carbon and nitrogen isotope analyses, is the site of Molle Pampa in the Lluta Valley, adjacent to the city of Arica, northern Chile. This site was excavated by Aufderheide and Santoro (1999) in order to determine whether two sub-groups of the Molle Pampa population could be differentiated on the basis of the chemical reconstruction of their diets.

Variations in food consumption determined by means of trace elements and stable isotope ratios provided information about the variability observed in pottery styles, currently used as symbols for ethnic and social identity or political affiliation. Aufderheide and Santoro (1999) thought that chemical dietary reconstruction might be useful in identifying patterns of food consumption more directly related to cultural and social boundaries, and even ethnicity.

Within the greater Molle Pampa site were two sub-areas where bones were scattered: Molle Pampa Este (MPE) and Molle Pampa Medio (MPM). Archaeological investigation at domestic structures determined that MPE was mostly occupied during the Late Period (c. 550–450 BP), while MPM was exclusively occupied around the Late Intermediate Period (c. 850–550 BP) (Aufderheide and Santoro 1999:240).

The stable carbon and nitrogen studies on 19 skeletal samples (ten from MPE and nine from MPM), from this site indicated that 'marine resources were exploited by both groups to a greater extent than the archaeological remains suggested'

(Aufderheide and Santoro 1999:249). This is another case that demonstrates the usefulness of an isotopic study to complement and crosscheck the data from a study employing standard archaeological methods.

A further study which uses stable carbon and nitrogen isotope analysis to examine marine versus terrestrial resource use, is research conducted by Knudson et al. (2012b) in the south-central Andes of Chile. This study used isotope analysis of enamel, bone and hair to reconstruct palaeodiet and palaeomobility in an adult male found buried along a pre-Columbian route between the northern Chilean coast to the inland Loa River Valley. The burial was dated to the Late Formative Period (c. 1949–1450 BP) and despite its inland location, archaeological evidence included grave goods that were consistent with that of coastal populations (Knudson et al. 2012b:435).

The results from the analysis indicated that δ^{13} C values demonstrated a mixture of C₃ and C₄ protein with the likely inclusion of a substantial amount of marine resources (Knudson et al. 2012b:443), indicating a mix of terrestrial and marine foods in the individual's diet. Stable nitrogen isotope values (δ^{15} N) between bone collagen and hair samples suggested that the individual was consuming foods from high trophic (marine animals) and low trophic (inland) level food sources, signifying that the individual was likely making frequent trips to and from the coast (Knudson et al. 2012b:443).

Another northern Chilean isotopic study was a masters project conducted by Petruzzelli et al. (2012) in northern Chile. Petruzzelli et al. (2012) conducted stable carbon and nitrogen isotope analysis on 26 human skeletal samples from two distinct geographic regions in northern Chile. The late Holocene (c. 4000–700 BP) archaeological sites of Azapa 71 (Az-71) in the Azapa Valley, and Pica-8, in the Tarapacá region of northern Chile, were examined to assess human diet and landscape use.

Results from the sites indicated that both populations retained diets based on terrestrial hunter-gatherer economies, with the addition of marine foods from mid to upper trophic levels and C_4 (maize) based resources during the later time periods (Petruzzelli et al. 2012:52). The outcomes of this research revealed the importance of using stable carbon and nitrogen isotope analyses, to understand the diets of past populations, as marine foods were found to be exploited to a far greater extent than the archaeological evidence for subsistence at the sites suggested (Petruzzelli et al. 2013:52). The results challenged the traditional archaeological data, which over-represented the use of both wild and farmed plant foods by these populations. Archaeological evidence identified at the sites suggested social interaction in the form of trade with highland and coastal populations. However, the social mechanisms explaining how different social groups had access to marine resources remain uncertain (Petruzzelli et. al. 2013:76).

Another study conducted in northern Chile, which was previously mentioned in the archaeological literature review of this thesis, is a preliminary isotope study on human bone collagen from the Caleta Vitor archaeological site (see Carter 2017; Roberts et al. 2013). Caleta Vitor is a coastal site, located approximately 29 kilometres south of the northern Chilean city of Arica (Figure 2.29). Skeletal remains from four of the sites in this area have been radiocarbon dated to between 4000 and 476 years BP (Roberts et al. 2013:2370).



Figure 2.29 View facing west across the coastal site of Caleta Vitor. Author's photo.

At this site 15 bone samples were collected for stable carbon and nitrogen isotope analysis. Stable carbon and nitrogen isotope values for the Caleta Vitor individuals reveal a diet consisting predominantly of marine foods from upper trophic levels (Roberts et al. 2013:2369). A comparison of the isotope analysis conducted on the Caleta Vitor samples compared to other nearby inland and coastal populations revealed clear dietary variability observable from the different geographic regions (Roberts et al. 2013:2370). Roberts et al. (2013:2370) conclude that the site of Caleta Vitor displays strong evidence for the retention of hunter-gatherer economies among these coastal inhabitants despite evidence that other inland populations were adopting agricultural economies at this time (Roberts et al. 2013:2369). This is an example of how stable carbon and nitrogen isotopic analyses can complement archaeological data.

Local Applications of Stable Carbon and Nitrogen Isotope Analysis

Stable carbon and nitrogen isotope studies in central Chile have been used to expand information on topics such as Chilean baseline resources and their isotope

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values, marine versus terrestrial resource use, resource use and the overrepresentation of particular food types in archaeology, the differential consumption of C₃ versus C₄ foods and the adoption of agricultural practices (see Falabella et al. 2007; Sanhueza and Falabella 2010; Swift et al. 2017; Tykot et al. 2009). Additional studies have focussed more in-depth on intra-community resource variation, such as differences in economic, political and social resource consumption (see Falabella et al. 2007; Sanhueza and Falabella 2010; Swift et al. 2010; Swift et al. 2017).

Baseline Resource Analysis

Analysis of baseline resources in the central Chilean region have provided stable isotopic values for terrestrial, lacustrine and marine resources, allowing for human isotopic comparison (see Falabella et al. 2007; Tykot et al. 2009). Modern baseline resources for wild and cultivated C₃ resources, C₄ resources and marine algae have been recorded from central Chile and can also be compared (by adding +1.5‰ to account for the Seuss Effect) to archaeological samples from central Chile (Stenhouse and Baxter 1979) (Table 2.1).

Table 2.1 Summaries (mean ± standard deviation) of stable carbon isotope baseline representative examples from Chile in comparison to the Fénix Archaeological Complex. Data table adapted from Falabella et al. (2007), Sanhueza and Falabella (2010) and Tykot et al. (2009).

Resource	Context	N	δ ¹³ Ccol (‰) X ± SD	Range
Marine Algae	Modern	2	-15.7 ± 2.3	-17.3, -14.0
Wild C ₃ Vegetation	Modern	14	-26.6 ± 2.9	-30.5, -21.0
Cultivated C ₃ Vegetation	Modern	6	-26.6 ± 1.6	-29.3, -24.7
Cultivated C ₄ Vegetation	Modern	1	-11.2	

Prior research into modern central Chilean baseline resources found that the δ^{13} Ccol of food resources to have a mean of -26.6‰ for non-gramineae (grass) C₃ plants and -22.3‰ for C₃ gramineae plants (see Falabella et al. 2007; Sanhueza and Falabella 2010; Tykot et al. 2009). After a +1.5‰ correction for the Seuss
Effect and +5.1‰ for diet to collagen fractionation, non-gramineae C_3 plants have a baseline value of -20.2‰ and gramineae C_3 plants have a baseline value of -15.9‰ in central Chile (see Falabella et al. 2007; Sanhueza and Falabella 2010; Tykot et al. 2009:162)

Furthermore, the modern central Chilean endpoint for C₄ cultivated resources (maize) has been found to be around -11.2‰ (Figure 2.30). After applying a +1.5‰ correction for the Seuss Effect and a +5.1‰ correction for diet to collagen fractionation, the baseline values for a diet based on 100% cultivated maize in central Chile sit at -4.6‰. However, it is unlikely that even populations heavily consuming maize will have a diet reflecting 100% C₄ protein. Additionally, according to climatic and environmental data, there should be no wild C₄ resources in central Chile (see Falabella et al. 2008; Tykot et al. 2009).



Figure 2.30 Graph showing baseline floral and faunal values for central Chile. Graph adapted from Falabella et al. (2007); Sanhueza and Falabella (2010) and Tykot et al. (2009).

Baseline marine signals for central Chile are reflected in the $\delta^{15}N$ values from marine plants and animals. Globally, marine hunters who consume resources from upper trophic levels will have $\delta^{15}N$ values between 15–20‰ (see Schoeninger 1995; Schoeninger and DeNiro 1984). However, northern Chilean coastal $\delta^{15}N$ values for marine resources have been found to range between 17.3–26.7‰ (see Roberts et al. 2013).

Temporal Analysis

Temporally, stable carbon and nitrogen isotopic evidence in central Chile indicates that Archaic Period (c. 10,000–2200 BP) diets in central Chile consisted of predominantly terrestrial C₃ resources, with the addition of marine protein (see Falabella et al. 2007; Sanhueza and Falabella; Swift et al. 2017). Following this, stable carbon and nitrogen isotopic evidence for Early Ceramic Period (c. 2200– 1000 BP) diets, indicated that populations during this time were eating mixed (C₃ and C₄) resources with the addition of wild terrestrial herbivores and marine resources from low-mid trophic levels. The practice of two different subsistence strategies contemporaneously saw one culture (the Bato) as hunter-gatherers, consuming a mix of terrestrial C₃ and moderate marine resources, while the other (the Llolleo) were becoming more sedentary and consuming C₄ resources, such as maize (see Falabella et al. 2007; Sanhueza and Falabella 2010).

Furthermore, stable carbon and nitrogen isotope analyses on samples from the Late Intermediate Period (c. 1000–550 BP), generally show an increase stable carbon isotope values, indicating an increase in the consumption of C_4 resources (see Falabella et al. 2007; Sanhueza and Falabella 2010). However, during the Late Period (c. 550–400 BP), stable carbon isotope values indicate a decrease in the consumption of C_4 resources, with a greater contribution from mixed C_3 resources (see Falabella et al. 2007).

Case Studies: Central Chile

One of the main published studies on stable carbon and nitrogen isotope analyses in central Chile is research by Falabella et al. (2007). Falabella et al. (2007) investigated the diet and landscape use of approximately 90 individuals from 32 archaeological sites in central Chile (Figure 2.31).



Figure 2.31 Map showing the locations of central Chilean sites referred to in the text. Map adapted from Falabella et al. (2007)

Results from their research indicated that individuals from the populations sampled had values illustrating low consumption of marine resources, at both inland and coastal sites, revealing a lack of marine adaptation for the coastal communities (Falabella et al. 2007:22). This is in contrast to archaeological evidence at the sites, such as mollusk, fish and marine mammal and bird bones, which suggested a much larger marine input than the isotopic results indicated (Falabella et al. 2007:22).

Moreover, stable carbon and nitrogen isotopic results established the introduction of C₄ cultigens into the diets of the individuals sampled. Falabella et al. (2017:22) found that individuals from the initial stages of the Early Ceramic Period (c. 2200–1750 BP) generally show no evidence of the consumption of maize, which is consistent with the archaeology at the sites. Furthermore, temporal and cultural results indicate that, while maize consumption is not

demonstrated for the Bato culture, the Llolleo population adopts maize during the Early Ceramic Period and the Aconcagua culture sees a rise in maize consumption during the Late Intermediate Period (c. 1000–550 BP) (Falabella et al. 2007:22). Additionally, geographic results indicate that Llolleo consumption of maize varies, with inland populations showing higher consumption of maize than coastal populations (Falabella et al. 2001:22).

During the Late Period (c. 550–400 BP), the Inka culture individuals show a fall in the consumption of maize compared to the Aconcagua individuals (Falabella et al. 2007:21). Possible explanations for this include the theory that not all of the maize harvested was consumed by the populations, with corn being used as a trade item (Falabella et al. 2007:21). Additionally, Falabella et al. (2007:23) also suggest that the consumption of marine algae may have enriched the Aconcagua populations' isotopic values, leading to results that indicate higher maize consumption than the Inka populations.

Further isotopic results for the Early Ceramic Period individuals indicate that the diets of the populations were based on wild and/or cultivated plants, with minimal animal protein (Falabella et al. 2007:23). This fall in animal protein consumption may mean that either the populations were no longer consuming animal protein or that the animals were eating corn stubble instead of C₃ plants, allowing a decrease in isotopic values (see Becker 1993; Falabella et al. 2007:23).

Finally, differentiation in maize consumption between males and females in the Aconcagua population was revealed from isotopic values. According to Falabella et al. (2007:23) males within the sample set had higher carbon values, indicating a higher consumption of maize, compared to the females. While the mechanisms for this require further research and are unexplained, it is possible that this could be due to marine algae consumption or cultural implications (Falabella et al. 2007:23).

This study serves to demonstrate that stable carbon and nitrogen isotope analysis is a useful tool for investigating past diet and culture. Results from this research show that groups occupying the same spaces with access to similar resources looked for different food combinations according to their cultural, technological and social organisation.

Another prominent stable carbon and nitrogen isotope study, conducted on human skeletal material in central Chile, is research by Sanhueza and Falabella (2010) on diet and mobility. Sanhueza and Falabella (2010:127) examined the bone collagen of 20 individuals from nine different (coastal, valley and cordillera) sites in central Chile from the late Archaic (c. 6000–2200 BP) to the Initial Early Ceramic Period (c. 2200–1750 BP) (Figure 2.32).



Figure 2.32 Map of central Chile showing sites referred to in the text. Map adapted from Sanhueza and Falabella (2010).

Isotopic results indicated that, despite the archaeological evidence (in the form of shellfish, fish and mammal bones), the late Archaic individuals did not incorporate significant amounts of marine resources into their diets (Sanhueza and Falabella 2010:130). Stable carbon and nitrogen isotope values suggest that marine

resources were consumed far less than the archaeological record implied, with isotope values demonstrating that marine resource consumption by coastal Archaic populations was occasional and variable (Sanhueza and Falabella 2010:130). Furthermore, individuals sampled from the Early Ceramic Period did not show the incorporation of animal protein into their diets, leading the researchers to question where they were getting their required protein from (Sanhueza and Falabella 2010:130). Isotopic evidence from the coastal sites challenges the notion that coastal dwelling populations were consuming marine resources by default and supports the idea that dietary choices were not purely related to geographic location but were carefully considered selections based on the available resources and culturally determined decisions.

Recent research that utilised stable carbon and nitrogen isotope analyses of human skeletal material is a study conducted by Swift et al. (2017) in central Chile. Swift et al. (2107) examined 24 human skeletal samples from nine different archaeological sites (coast and interior, Figure 2.33), from the Early Ceramic to Late Period (c. 2200–400 BP).



Figure 2.33 Central Chilean sites relevant to Swift et al.'s (2017) research. Map adapted from Swift et al. (2017).

Overall results indicated that stable carbon and nitrogen isotope ratios for coastal inhabitants demonstrated values indicating a diet based on terrestrial resources with the addition of lower tropic level marine resources, such as seaweed and mollusks (Swift et al. 2017:34). Conversely, results for the inland populations sampled demonstrated stable carbon and nitrogen isotopic values indicative of a terrestrial diet, low in animal proteins or inclusive of nitrogen-fixing legumes (Swift et al. 2017:34).

Furthermore, temporal results indicated that there was a marked increase in stable carbon isotope values between the Early Ceramic and Late Intermediate Periods (c. 2200–550 BP), and again into the Late Period (c. 550–400 BP), indicating increased maize consumption over time (Swift et al. 2017:29).

Summary

Stable carbon and nitrogen isotope analyses have been used globally, regionally and locally to investigate issues pertaining to marine versus terrestrial resource use, the differentiation between C₃ and C₄ resource use, the introduction to agricultural practices and differential consumption of resources temporally, geographically and socially. Case studies used in this section of the literature review are by no means exhaustive, but instead serve to illustrate the kinds of information that can be obtained from using stable carbon and nitrogen isotope analyses in different areas of the world.

Published stable carbon and nitrogen isotopic studies in central Chile are limited, with a few main authors reporting for a range of sites. Multiple isotope studies conducted have been split into stable carbon and nitrogen and oxygen studies for the purpose of this research. The following section outline relevant stable oxygen isotope research and case studies.

Oxygen Applications: Case Studies

Stable oxygen isotope analysis of human remains has been used to broadly examine the mobility of prehistoric humans through their bones and teeth. Archaeological studies involving stable oxygen isotope analysis have been used to address a range of issues including, but not limited to, residential mobility, migration patterns, intra-community social relations, sedentism and territoriality (see Beard and Johnson 2000; Budd et al. 2001, 2003; Gil et al. 2011; Hodell et al. 2004; Knudson 2009; Knudson et al. 2012b; Müller et al. 2003; Pate 1995, 2000; Pate et al. 2002; Price et al. 2000; Ugan et al. 2012). These studies have been conducted through a baseline examination of climatic and water oxygen values (SMOW) compared to human oxygen values ($\delta^{18}O_{ap}$) (see Fricke et al 1998; Longinelli 1984; Luz et al. 1990). Stable oxygen isotope analyses have been used globally to examine issues such as the identification of a foreign individual within a burial population (see Knudson et al. 2012a, 2012b), the mobility of an individual at the start of their life (through analysis of dental material) (see Budd et al. 2004; Knudson et al. 2012b; Turner et al. 2009) and the mobility of an individual towards the end of their life (through analysis of skeletal material) (see Budd et al. 2004; Knudson et al. 2012b; Kohn et al 2003; Müller et al. 2003; Rubenstein and Hobson 2004).

This section of the literature review examines archaeological issues pertaining to stable oxygen isotope analysis on a global level with case studies supporting these applications. From this, the kind of research questions that can be answered using stable oxygen isotope analysis will be illustrated, starting with case studies from the Ireland, North America and Central America.

Ireland

Stable oxygen isotope analysis in Ireland has been used in several different localities in order to identify the movements of people across the landscape and examine issues relating to the identification of foreigners to a burial population (see Hughes et al. 2014; Knudson et al. 2012a).

One case study where stable oxygen isotope analysis has been used to identify the geographic origins of individuals, is an investigation by Knudson et al. (2012a) into Viking settlement in Dublin. Knudson et al. (2102a) examined the dental and skeletal remains from 11 individuals from four sites (Fishamble Street II, Fishamble Street III, St John's Lane and Wood Quay), located in Dublin (Figure 2.34). The sites ranged temporally from the 9th to 12th centuries AD, covering a period of Viking expansion. Human material culture and biodistance (DNA) studies of the populations in the area, both suggested that the population consisted of both immigrant and indigenous peoples (Knudson et al. 2012a:308).



Figure 2.34 Map of Ireland, showing the location of Dublin. Map adapted from Google Maps.

Oxygen isotope results indicated that most individuals revealed relatively homogenous δ^{18} O values, representing the same, or similar, sources of geographic origins (Knudson et al. 2012a:317). Conversely, one individual from an early phase of settlement, is a clear outlier, demonstrating different δ^{18} O values in the first years of life (Knudson et al. 2012a:318). Overall, the stable oxygen isotope results reflect acculturation in Dublin, rather than indicating immigrants to the burial population (Knudson et al. 2012a:318). This is one example where stable oxygen isotope analysis has been used to identify the origins of a burial population and test archaeological theories.

North America

Stable oxygen isotope analysis in North America has been utilised to examine a variety of issues, including, but not limited to, identification of foreigners within a burial population and the mobility of individuals (see Culleton et al. 2016; Eerkans et al. 2013).

One study that examines the mobility of individuals during their lives, is research conducted by Eerkens et al. (2013) in central California. Eerkans et al. (2013:475) used stable oxygen isotope analysis to trace the mobility of three prehistoric (c. 500 BP) individuals found buried at the archaeological site of YOL-117 (Figure 2.35). Archaeological evidence at the site indicated that the individuals were killed as part of a single event in violent circumstances (Eerkans et al. 2013:475).



Figure 2.35 Map of California illustrating the locations of the main site, YOL-117 and the surrounding archaeological sites. Map adapted from Eerkens et al. (2013).

Stable oxygen isotopic results suggest that two of the three individuals were born in the area. Additionally, δ^{18} O values indicate that it is likely all three of the

individuals spent their teenage years near the site (Eerkans et al. 2013:478). Conversely, δ^{18} O values show that the three individuals lived elsewhere, likely north of the Sacramento River, for their adult years, and returned to the area shortly before death (Eerkans et al. 2013:479). This is one study that illustrates the general use of stable oxygen isotope analysis to examine the mobility of prehistoric humans.

Central America

Stable oxygen isotope analysis in Central America has been used to widely examine theories pertaining to population movement and intra-community relations (see Price et al. 2018; Rand 2017; White and Spence 1998). One study where population movement and local stability was tested using stable oxygen isotope analysis was research by White and Spence (1998) in Mexico.

White and Spence (1998:646) used stable oxygen isotope analysis to examine the bone phosphate of 22 individuals from the site of Tlajinga 33, Teotihuacan (Valley of Mexico), and 16 individuals from the site of Monte Alban from the Valley of Oaxaca (Figure 2.36).



Figure 2.36 Map showing the locations of the two areas in Mexico referred to in the text. Map adapted from White and Spence (1998).

Stable oxygen isotope results demonstrate uniformity throughout the values at each of the sites, revealing that there was limited movement of individuals between the two sites (White and Spence 1998:648). Additionally, results showed that there was no temporal variability at either of the sites, suggesting environmental stability in the region (White and Spence 1998:653). This case study demonstrates the use of stable oxygen isotope analysis to investigate variation in values from different communities.

Regional Applications of Stable Oxygen Isotope Analysis

Regional applications of stable oxygen isotope analysis in South America have been used to research the mobility of populations (see Knudson and Price 2007; Toyne et al. 2014; Ugan et al. 2012), reconstruction of mobility during an individual's lifetime (see Knudson et al. 2012b) and the influence of economy on human population movement (see Gil et al. 2011). This section of the literature review explores these topics with reference to case studies from Peru, Argentina and northern Chile.

Peru

One study where stable oxygen isotope analysis was used to examine evidence of mobility in a burial population is research conducted by Toyne et al. (2014) at the prehispanic Peruvian site of Huacas de Moche (Figure 2.37). Toyne et al. (2014) examined the geographic identities and relocation history of individuals interred in elite burials and sacrificial contexts using phosphate oxygen isotope composition. Stable oxygen isotope analysis was conducted on the tooth enamel and bone apatite of 34 individuals from the early Late Intermediate Period (c. 1850–1100 BP).



Figure 2.37 Map showing the location of sites relevant to the Peruvian case study. Map adapted from Toyne et al. (2014).

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Results demonstrated the possible presence of a patrilocal residence pattern, with male δ^{18} O values reflecting local water compositions and females reflecting more variable δ^{18} O compositions, possibly moving to the site after a childhood elsewhere (Toyne et al. 2014:24). However, one male individual demonstrated δ^{18} O values reflecting consumption of non-local water. Toyne et al. (2014:25) suggest that this individual may have travelled to another locale and returned to the Moche valley before death or died elsewhere and was returned for burial. Furthermore, the early sacrificial victims consisted primarily of local individuals, with a greater inclusion of non-locals during later Moche state development (Toyne et al. 2014:26). This study demonstrates the use of stable oxygen isotope analysis to examine intra-community variation from a burial population.

Argentina

Stable oxygen isotope analysis was conducted on the bone carbonate of 71 individuals by Gil et al. (2011) in central western Argentina (Figure 2.38). Gil et al. (2011) examined changes in human residential mobility during the late Holocene, with the expectation that there would be a change in human population movement with the introduction of domesticates such as maize (*Zea mays*), gourd (*Cucurbita* sp.) and beans (*Phaseolus* sp.).



Figure 2.38 Map showing sites relevant to the Argentinean case study. Map adapted from Gil et al. (2011).

Contrary to expectations, stable oxygen isotope results revealed that there were no apparent differences among the populations sampled, with significant variations in δ^{18} O values seen across all samples, both geographic and temporal (Gil et al. 2011:36). These results suggest that the populations throughout central western Argentina were all highly mobile, with no current evidence for changes in mobility subsequent to the introduction of cultigens (Gil et al. 2011:37).

Additionally, Gil et al. (2011:36) do not believe that the patterns (or lack of) can be attributed to variations in temperature and precipitation, as current data suggest that there is little evidence for significant palaeoclimatic variation in the last 6000 years in the area (see Zárate et al. 2010). This is one case study which illustrates the use of stable oxygen isotope analysis to cross-check assumptions made from archaeological data.

Northern Chile

One study that incorporated stable carbon, nitrogen, oxygen and strontium isotope analysis, is a project conducted in the south-central Andes of northern Chile by Knudson et al. (2012b). This study used isotope analysis of enamel, bone and hair to reconstruct palaeodiet and palaeomobility in an adult male found buried along a pre-Columbian route between the northern Chilean coast to the inland Loa River Valley (Figure 2.39). The burial was dated to the Late Formative Period (c. 1949–1450 BP) and despite its inland location, archaeological evidence included grave goods that were consistent with that of coastal populations (Knudson et al. 2012b:435).



Figure 2.39 Map showing the location of the study area (hashed box) of the individual in northern Chile. Map adapted from Knudson et al. (2012b).

The results from the stable oxygen isotope analysis were variable between the dental samples and the skeletal samples, suggesting that the individual was born on the Pacific coast of the Atacama, moved around throughout their lifetime and Bianca Waldie 131 died in the south-central Andes study area (Knudson et al. 2012b:445). Knudson et al. (2012b:446) argue that the individual was regularly moving from the coast to the highlands. This hypothesis is strongly supported by both the traditional archaeological and isotopic evidence. This study demonstrates the ability of isotopic data to identify patterns of mobility in prehistoric people using multiple isotopic analyses.

Local Applications of Oxygen Isotope Analysis

Stable oxygen isotope studies in central Chile have been used to explore issues such as the mobility of populations (see Falabella et al. 2007; Sanhueza and Falabella 2010), the lifetime mobility of individuals (see Falabella et al. 2007) and intra-community geographical variations (see Falabella et al. 2007). Published oxygen isotope studies in central Chile have been limited to date, but this section presents the available studies from the area.

One of the main local studies that includes the use of stable oxygen isotope analysis, is research conducted by Falabella et al. (2007) on the reconstruction of settlement patterns of prehispanic ceramic societies from central Chile. Falabella et al. (2007:8) examined 90 individuals from populations throughout central Chile (coastal, valley and cordillera), from the Initial Early Ceramic Period (c. 2200–1750 BP), through to the Late Period (c. 550–400 BP) (Figure 2.40). Additionally, an examination of the cultural complexes, such as the Bato (c. 1750–1000 BP), Llolleo (c. 1550–1000 BP), Aconcagua (c. 1000–550 BP), and Inka (c. 550–400 BP) were investigated to identify potential spatial and social mobility strategies.



Figure 2.40 Map showing the locations of central Chilean sites referred to in the text. Map adapted from Falabella et al. (2007).

Stable oxygen isotope analysis results indicated values consistent with baseline values for all locations (coastal, valley and cordillera), meaning that it is likely that individuals sampled from these areas were locals and lived regularly in only one of these environments (Falabella et al. 2007:19). However, during the Aconcagua cultural phase (c. 1000–600 BP), δ^{18} O values for individuals from the valley site of Maria Pinto demonstrated isotopic values similar to coastal populations (Falabella et al. 2007:13). One reason for this may be that the inhabitants of the site were moving between the valley and the coast. This would be consistent with δ^{13} C and δ^{15} N isotope values and archaeological evidence which suggest the possibility of seasonal coastal camps from the interior (see Falabella et al. 2003). Overall, stable oxygen isotope values revealed that the populations in central Chile likely lived in defined territories throughout their lives, with minimal movement between environments.

Another prominent central Chilean isotope study which incorporated the use of stable oxygen isotope analysis, was conducted by Sanhueza and Falabella (2010) on diet and mobility at the end of the Archaic Period and the initial stage of the Early Ceramic Period in central Chile. Sanhueza and Falabella (2010) examined 20 human skeletal samples, using stable carbon, nitrogen and oxygen isotope analysis, from nine archaeological sites on the coast, in the valleys and the Andean cordillera of central Chile (Figure 2.41).



Figure 2.41 Map showing the location of archaeological sample sites in central Chile. Map adapted from Sanhueza and Falabella (2010).

Stable oxygen isotope results indicated that δ^{18} O values for individuals from the coastal sites were consistent with values from local waters, implying that the individuals occupying these coastal sites were not travelling inland (Sanhueza and Falabella 2010:132). Similar stable oxygen isotope results were found for individuals from the inland valleys, where δ^{18} O skeletal values were consistent with inland local waters (Sanhueza and Falabella 2010:133).

Contrary to the coastal and inland lacustrine valley results, the δ^{18} O values for skeletal samples from sites along the Andean cordillera were varied, revealing values that did not correspond with local waters (Sanhueza and Falabella

2010:133). Sanhueza and Falabella (2010:133) proposed that the individuals from these sites were likely either travelling through different regions or inhabited different places during their lives. Overall, δ^{18} O results indicated values representing evidence of restricted mobility for coastal and valley individuals and a greater mobility for individuals sampled from the highlands (Sanhueza and Falabella 2010:134). This is a good example of local δ^{18} O results in central Chile that can be compared to the results of this research project.

Summary

Stable oxygen isotope analysis has been used around the world to examine a range of issues concerning migration patterns, residential mobility, intra-community social relations, sedentism and territoriality (see Beard and Johnson 2000; Budd et al. 2001, 2003; Gil et al. 2011; Hodell et al. 2004; Knudson 2009; Knudson et al. 2012b; Müller et al. 2003; Pate 1995, 2000, 2006; Pate et al. 2002; Price et al. 2000; Ugan et al. 2012). However, published stable oxygen isotopic studies in central Chile are small in number, with only a few main authors reporting for a range of sites.

Literature Review Summary

This literature review examined the fundamental theories relating to human diet and landscape use throughout the Holocene. The literature review was split into two parts in order to arrange the information in the most clear and concise way and to direct the reader to the theories behind the research and then the practical aspects of the research.

Overall, this literature review conducted an examination of the archaeological, isotopic and elemental aspects of human diet and landscape use on global, regional and local levels, with reference to relevant case studies. From this, information about diet and landscape use was explored to provide contextual information for this research project on the archaeological, isotopic and elemental analysis of the population at the Fénix Archaeological Complex in central Chile.

Overview

The study area for this research project is located in central Chile, South America. Chile occupies a long, thin strip of land between the Andes mountain range and the Pacific Ocean (Figure 3.1). The geography of Chile is varied, with the Atacama Desert located to the north, the Andes to the east, the Pacific coast to the west and Patagonia to the south. Prehistoric populations in Chile living in different environments had their own subsistence and cultural systems, which will be explored in this chapter. Combined with chronometric dating methods (such as ¹⁴C and TL), relative dates based on cultural chronologies allowed the establishment of timelines, or chronological periods, for populations living throughout Chile.



Figure 3.1 Map of the Fénix study area (32°S, 71°W) in relation to geographical features referred to in the text.

The inhabitants of the Fénix Archaeological Complex were located in Quintero Bay, central Chile. Over time many different cultural phases are evident at the complex, which dates from the mid-late Archaic Period to the Late Intermediate Period (c. 7000–550 BP). The focus of this research project is the four sites located within the coastal Fénix Archaeological Complex, and its inhabitants.

Climate, Environment and Resources on the Central Chilean Coast

Climate

The climate in central Chile is classified as 'Mediterranean' (*Csb*) according to the Köppen (1931) climate classification, with warm, dry summers and cool, humid winters. The moisture in central Chile comes directly from the west, over the Pacific Ocean (Jenny et al. 2002:3). Modern day average rainfall in central Chile is approximately 545 mm annually (Jenny et al. 2002:3).

In the past, the mapping of Holocene central Chilean precipitation and temperature (through tree rings, ice cores, fossil pollen, ocean/lake sediments and historical data), has been problematic due to a lack of suitable data to complement high-resolution palaeoclimatic studies (Villa-Martínez and Villagrán 1997:392). However, more recent studies have been conducted on the available material, which has allowed the establishment of a picture of Holocene central Chilean climate (see Heusser 1990; Lamy et al. 1999; Maldonado and Villagrán 2006; Montecinos and Aceituno 2003; Veit 1996; Villa-Martínez and Villagrán 1997).

Palaeoclimatic data from central Chile indicate an early Holocene wet phase, from approximately 10,000 cal BP to 8700 cal BP (Maldonado and Villagrán 2006:257). Following the wet phase, marine sediments off the coast of central Chile (33°S), and fossil pollen and lake sediment evidence from the sites of Laguna Aculeo (see Jenny et al. 2002), Quintero (see Villa-Martínez and Villagrán 1997) and Palo Colorado (see Maldonado and Villagrán 2006) suggest an arid phase between approximately 8700 cal BP to 5700 cal BP (Maldonado and Villagrán 2006:257) (Figure 3.2). Additionally, the start of the El Niño

Southern Oscillation (ENSO) climatic pattern, between approximately 6000 and 5000 BP, saw an increase in precipitation, with data from sites such as Palo Colorado and Quintero also indicating an increase in moisture between approximately 5000 cal BP and 3000 cal BP (see Maldonado and Villagrán 2006; Villa-Martínez and Villagrán 1997).



Figure 3.2 Map of palaeoclimatic sites referred to in text. Map adapted from Maldonado and Villagrán (2006) and Villa-Martínez and Villagrán (1997).

Following the increase in moisture, a short arid phase is indicated by palynological records at the site of Palo Colorado (see Maldonado and Villagrán 2006) between 3000 and 2200 cal BP. However, fossil pollen and lake sediment data from the Quintero swamp indicate increasingly wet conditions starting around 4000 BP and continuing throughout the late Holocene, with the establishment of the forest and lagoon system that exists there today around 2000 BP (Jenny et al. 2002; Villa-Martínez and Villagrán 1997:399).

Between 2000 BP and present day, precipitation was extremely variable (see Jenny et al. 2002; Maldonado and Villagrán; Villa-Martínez and Villagrán). Maldonado and Villagrán (2006:257) propose that the variable precipitation suggests a greater ENSO frequency and prevailing wet conditions. Furthermore, during the last 50 years, modern annual

precipitation in central Chile has been mapped, through fossil pollen, lake sediments and historical data, with results indicating that high annual rainfall corresponds with the El Niño Southern Oscillation (Jenny et al. 2002:6).

El Niño Southern Oscillation is a climatic pattern that occurs across the Pacific Ocean, characterised by variations in the tropical eastern Pacific sea surface temperature (SST) and air surface pressure in the western Pacific (Williams et al. 2008:246). There are two variations: the El Niño Phase, which is the warm oceanic phase that accompanies high air surface pressure in the western Pacific, and the La Niña Phase, which is the cold oceanic phase that accompanies low air surface pressure in the western Pacific. These two phases have been known to interrupt the seasonal oceanic system in central Chile, known as the Humboldt Current System (Williams et al. 2008:246) (Figure 3.3).



Figure 3.3 Map illustrating the location of the Humboldt Current System, Pacific coast, South America.

The Humboldt Current System (HCS) is a system of cold, nutrient-rich oceanic waters and nutrient-rich subsurface waters upwelled and transported northwards (Thiel et al. 2007:198). The upwelling of these waters in this region results in extremely high primary production from fisheries through the large availability of marine biomass that feed on the nutrients (Thiel et al. 2007:196). Thus, the HCS extends along the western coast of the South American continent, from around the equator to approximately 42°S, and is one of the most productive marine ecosystems on earth (Thiel et al. 2007:196).

While the northern Pacific upwelling events are continuous throughout the year, in central Chile they are mainly concentrated in the spring and summer months (Strub et al. 1998). However, as mentioned above, this cycle is interrupted and suppressed by the ENSO climatic phenomena, which disrupts this regional pattern with the influx of warmer, nutrient-depleted water from the equatorial regions, and complicates ecological processes along the central Chilean coast (see Montecinos and Gomez 2010).

The onset of ENSO on the western South American coast around 6000 to 5000 BP reduced the upwelling of the nutrient-rich, cold Humboldt Current by enabling the flow of warmer Pacific water south from the equatorial regions (see Roberts et al. 2013; Sandweiss et al. 1996; Thiel et al. 2007; Williams et al. 2008). It is possible that the disruption of the Humboldt Current System by ENSO affected the marine ecosystem in central Chile to such an extent that the marine biomass was not utilised as a reliable resource. This, in combination with the plentiful terrestrial and lacustrine resources along the central Chilean coast, may have led to a greater use of interior resources and less reliance on marine resources (see Planella and Tagle 2004; Planella et al. 2011; Sanhueza and Falabella 2010). This contrasts with the northern Chilean coast, which is bounded by the Atacama Desert, reducing the amount of terrestrial and lacustrine resources and forcing the populations to rely more heavily on coastal and marine resources. These environmental differences may account for observed differences in the use of marine and coastal resources by hunter-gatherers along the Chilean coast (see Falabella et al. 2007; Roberts et al. 2013; Sanhueza and Falabella 2010). It has further been suggested that ENSO was a possible triggering mechanism for the move from coastal hunter-gathererfishers to inland valley sites and the adoption of agricultural practices (Ramirez et al. 2001:6). It is possible that similar effects were seen on the central Chilean coast, which

would explain why isotopic studies conducted on Archaic hunter-gatherers on the central Chilean coast demonstrate values that reflect a terrestrial diet, with minimal marine contributions (see Sanhueza and Falabella 2010).

Environment

Central Chile, between the areas of approximately 30 to 40 degrees south, is known as an intermediate environment, as it sits in the middle of mixed environments (see Galarce and Santander 2011). Central Chile is bounded to the west by the Pacific coast, to the east by the Costa de Cordillera and further east by the Cordillera de los Andes. To the north of central Chile lies the Atacama Desert, one of the driest places on earth with less than 1 mm of rain annually, and to the south lies the cool and dry environment of the region of Patagonia (Figure 3.4). It is due to this intermediate environment that past central Chilean populations could exploit mixed resources (marine, lacustrine and terrestrial) (Sanhueza 2013:49).



Figure 3.4 Map of South America displaying the Quintero Bay study area in context.

Quintero Bay, Valparaíso Region, Central Chile

The Bay of Quintero, located in the Valparaíso Region of central Chile (at 32°S), is a relict swamp site on the central Chilean coast (Jenny et al. 2002:3) (Figure 3.5). Modern day Quintero is a shallow bay, facing approximately northwest, with small streams draining into the bay, which generate lagoons and wetlands in the area (Cartagena et al. 2013:46).

During the middle Holocene (c. 6000–5000 BP), sea levels along the Pacific coast of South America reached levels 2–5 m higher than that of the present day due to deglaciation after the Last Glacial Maximum (see Clark and Mix 2002; Villa-Martínez and Villagrán 1997:398). Sea levels started to drop from around 5000 BP and gradually decreased back to their current level (Villa-Martínez and Villagrán 1997:398). During this time, the sealevel rise, and consequent rise in the water table, led to the beginning of the development of the lagoon system that currently exists in Quintero Bay (Villa-Martínez and Villagrán 1997:399).



Figure 3.5 The port of Quintero, Valparaíso region of central Chile (2014). Author's photo.

The Fénix Archaeological Complex is located on the marine terrace system of the Quintero Bay area, between lagoon and forest areas (Galarce and Santander 2011:8). It is due to this environment that inhabitants of the area, during the mid-late Holocene, are thought to have exploited mixed microenvironments, with combined access to coastal Bianca Waldie 142

resources, based on faunal remains found at archaeological sites, in the Bay of Quintero and nearby permanent lagoon and forest areas (Galarce and Santander 2011:8).

Resource and Landscape Use

The landscape of central Chile is varied, with coasts (Figure 3.6), valleys and mountains all existing within a narrow strip of land. Due to the variable geography of the country, different types of resources were available in each area. This variability provided a plethora of natural resources for highly mobile populations.



Figure 3.6 A view from the coast, Valparaíso region of central Chile (2014). Author's photo.

Resource Use

The Pacific Coast of Chile is generally known for its rich resources, with seaweed, shellfish, fish, sea birds and marine mammals all being available to hunter-gatherers in the region (Santoro et al. 2005:248). The available data from central Chilean coastal sites, such as Punta Caraumilla and LEP-C (Falabella and Planella 1991; Ramírez et al. 2001) (see Literature Review for current synopsis), suggest that the central coast began to be occupied by groups of terrestrial hunter-gatherers from around 8800 BP (during the early Archaic Period), who eventually learned to exploit the spectrum of coastal resources (Sanhueza and Falabella 2010:127) (Table 3.1).

Table 3.1 Species found at central Chilean archaeological sites. Table adapted from multiplesources (see Falabella et al. 2007; Galarce and Santander 2011).

ECP= Early Ceramic Period.

Common name	Species	Region	Site	Context
(Spanish name)				
Marine Fauna		-		-
South American Sea lion	Otaria spp.	Coast	Arévalo-2	Bato
	Otaria spp.	Coast	Fénix 3	ЕСР
Chilean sea urchin (Erizo	Loxechinus sp.	Coast	Fénix 3	ECP
blanco)	-			
Chiton (Chitón)	Chiton magnificus	Coast	Fénix 3	ECP
Black snail (Caracol negro)	Tegula atra	Coast	Fénix 3	ECP
	Tegula atra	Coast	Maitencillo	Current
Giant mussel (Choro	Choromytilus chorus	Coast	Fénix 3	ECP
zapato)				
	Choromytilus chorus	Coast	Maitencillo	Current
Giant wedge clam (Macha)	Mesodema donacium	Coast	Maitencillo	Current
	Mesodema donacium	Coast	Fénix 3	ECP
Chilean abalone (Loco)	Concholepas concholepas	Coast	Maitencillo	Current
Chilean croaker (Corvina)	Cilus gilberti	Coast	San Antonio	Current
	Cilus gilberti	Coast	Fénix 3	ECP
Marble fish (Jerguilla)	Aplodactylus punctatus	Coast	San Antonio	Current
Pacific jack mackeral	Trachurus symmetricus	Coast	San Antonio	Current
(Jurel)				
	Trachurus symmetricus	Coast	Fénix 3	ECP
South Pacific hake	Merluccius gayi	Coast	San Antonio	Current
(Merluza)				
White mouth croaker	Micropogonia furnieri	Coast	L. Matanzas	Aconcagua
(Roncador)				
Cormorant	Phalacrocorax sp.	Coast	Fénix 3	ECP
Penguin	Sphenicus spp.	Coast	Fénix 3	ECP
Lake Fauna				
Coypu (Coipo)	Myocastor coipus	Coast	Arévalo-2	Bato
	Myocastor coipus	Valley	Cuchipuy	ECP
	Myocastor coipus	Coast	Fénix 3	ECP
Helmeted water toad	Caudiverbera	Coast	TV-1	Aconcagua
(Rana)	caudiverbera			
	Caudiverbera	Coast	Fénix 3	ECP
Terrestrial Fauna				
Llama (Guanaco)	Lama auanicoe	Highland	Escobarinos	Aconcagua
	Lama auanicoe	Coast	Fénix 3	ECP
	Lama guanicoe	Highland	Queltehues	Archaic
	Lama guanicoe	Coast	TV-1	Aconcagua
	Lama guanicoe	Coast	Arévalo-2	Bato
	Lama guanicoe	Vallev	La Palma	Bato
	Lama auanicoe	Valley	La Grania	Llolleo
Marine Vegetation				
Bull kelp (<i>Cochavovo</i>)	Durvillea antartica	Coast	Con Con	Current
Sea weed (Luche)	Porphyra columbina	Coast	Maitencillo	Current
Wild Vegetation				

Chilean puya (Chagual)	Puya chilensis	Coast/Highlands	Mercado	Current
Chilean tussockgrass	Nasella chilensis	Highlands	С.	Current
(Paja)			Fallerones	
Boldo	Peumus boldus	Highlands	Arryán	Current
Chilean acorn (Peumo)	Cryptocaria alba	Highlands	Arryán	Current
	Cryptocaria alba	Coast	Fénix 3	ECP
	Cryptocaria alba	Coast	Maitencillo	Current
	Cryptocaria alba	Valley	Santiago	Current
Spring onion (Cebolleta)	Brodiaea porrifolia	Coast	Maitencillo	Current
Peppertree (Molle)	Schinus latifolius	Coast	Maitencillo	Current
Chilean wine palm (Palma)	Jubaea chilensis	Coast	Viña del	Current
			Mar	
	Jubaea chilensis	Coast	Fénix 3	ECP
Carob tree (Algarrobo)	Prosopis chilensis	Valley	Antumapu	Current
Myrtle (Arryán)	Luma apiculata	Valley	Santiago	Current
Tarweed (Madi)	Madia sativa	Valley	Quincanque	Current
Chilean wine berry	Aristotelia chilensis	Valley	Linares	Current
(Maqui)				
Cultivated Vegetation				
Wild potato (Papa	Solanum maglia	Coast	Maitencillo	Current
cimarrona)				
Pumpkin (Calabaza)	Lagenaria sp.	Valley	Chada	Current
Maize (Maíz caragua)	Zea mays	Valley	VI Región	Current
Pallar bean (Pallar flor	Phaseolus lunatus	Valley	VI Región	Current
blanca)				
Potato (Papa)	Solanum tuberosum	Valley	Santiago	Current
Quínoa	Chenopodium quinoa	Valley	Paredones	Current
Squash (Zapallo hoyo)	<i>Cucurbita</i> sp.	Valley	VI Región	Current

As noted previously, the Fénix Archaeological Complex is located on the coast in a relict lagoon (Galarce and Santander 2011:8). Osteofaunal evidence at the complex indicates marine, as well as lacustrine and terrestrial resources, were utilised throughout the complex during the late Holocene in the Early Ceramic Period (c. 2200–1000 BP) (Galarce and Santander 2011:44). Fragmented marine shells were also found in stratigraphic layers correlating to the Archaic Period (Galarce and Santander 2011). However, stable carbon and nitrogen isotopic data from other central Chilean coastal sites, such as Punta Caraumilla and LEP-C, reveal that despite marine molluscs being found within the archaeological sites, Archaic populations were not actually consuming a significant amount of marine foods (see Falabella et al. 2007; Sanhueza and Falabella 2010). Sanhueza and Falabella (2010:134) suggest that to more fully explore this discrepancy between the archaeological and isotopic data, future research should involve a larger sample of individuals to determine whether the results reflect anomalies within the population or are characteristic for the Archaic Period. Carbon and nitrogen isotopic analyses conducted on skeletal remains at other central Chilean sites have provided evidence demonstrating the consumption of a broad range of available terrestrial resources (Sanhueza and Falabella 2010:127). Wild (C₃) terrestrial plants (such as temperate shrubs, trees and grasses) are dominant in this area, due to the Mediterranean-like climate of the region (Sanhueza and Falabella 2010:128). However, maize (*Zea mays*), a C₄ cultivated plant, has also been found at many archaeological sites throughout central Chile, from the Early Ceramic Period through to the present day (see Literature Review for C₃ vs C₄ plant details). Based on isotopic analyses from Archaic coastal sites, it was inferred that populations living along the coast during the Archaic Periods (c. 10,000–2200 BP) did not heavily exploit marine resources but instead, the incorporation of marine resources into their diet were occasional, variable and likely used to further supplement the consumption of wild terrestrial plants and animals (Sanhueza and Falabella 2010:134).

Landscape Use: Geography and Mobility

The landscapes in central Chile are highly variable with the Pacific coast at the western extreme, adjacent to the mountainous Cordillera de Costa to the east of the coast, central valleys, and the highland Cordillera de los Andes bounding the east. Archaeological sites have been found throughout these landscapes and have yielded evidence of human mobility (see Cornejo and Sanhueza 2011; Falabella and Planella 1991; Falabella et al. 2007; Sanhueza and Falabella 2010) and resource use during the Holocene (Figure 3.7).



Figure 3.7 Map of the central Chilean area illustrating a selection of key archaeological sites. Map adapted from Planella et al. (2005), Sanhueza (2013) and Sanhueza and Falabella (2010).

Differences in the geology and altitude in central Chile, make the region ideal for oxygen isotope analyses. This is because there is great variation in central Chile's δ^{18} O values throughout the landscape due to variation in the groundwater resulting from changes in altitude and temperature between the coastal and inland areas (Sanhueza and Falabella 2010:128).

An example of how landscape use has been investigated by oxygen isotope analysis previously is the study conducted by Sanhueza and Falabella (2010). Their oxygen isotope results from human femoral bone from the Archaic Period have suggested that these coastal hunter-gatherers were moving in confined areas directly adjacent to the coast and exploiting a range of available terrestrial resources in the area, while consuming limited quantities of marine resources (Sanhueza and Falabella 2010:132; see Literature Review for detailed case studies).

Summary

The 'Mediterranean' climate in central Chile allows for an environment of mixed resources. Marine, lacustrine and terrestrial food resources have been found at archaeological sites on the Chilean coast, in the valleys and in the highlands of this geographically variable region, with a dominance of C_3 terrestrial vegetation. Environmental disruptions, such as ENSO, throughout the region have previously been used to explain disruptions in resource and landscape use seen at archaeological sites (see Sanhueza and Falabella 2010; Thiel et al. 2007). The Quintero Bay area, in which this study is located, has the advantage of having an associated palaeoclimatic study providing local information on both the palaeoclimate of the Holocene and the environment of the swamp area. This will allow comparisons between the Fénix Archaeological Complex and other sites where similar studies have been conducted.

Chilean Site Chronology

Overview

Chilean site chronology is fundamentally organised into time periods characterised by significant economic, political or technological developments (e.g. The Archaic Period, Early Ceramic Period, Late Intermediate Period and Late Period). Additionally, relative chronology in Chile has been based on the stratigraphic location of material remains, relying on a time/depth correlation for the artefacts at any given site (see Ardila Calderon 1992; Borrero 1989; Lanata 1996). Cultural phases, such as Bato, Llolleo, Aconcagua and Inka, have been assigned to time periods using a culture historical approach — where material remains are classified according to stylistic features, with the idea that those stylistic features were directly correlated with specific groups and thus could be used to form a cultural timeline (see Steward 1942; Trigger 2006). For example, in central Chile, the presence of an orange clay bowl with black designs painted over it would likely be assigned to the Aconcagua cultural phase, which was situated during the Late Intermediate Period (c. 1000–550 BP). Under the culture historical framework, the presence of different styles of material culture within a single context was interpreted as

reflecting multiple cultural groups living in the same locations (e.g. Bato and Llolleo cultural groups) (see Politis 2003).

Construction of broad regional chronologies is necessary for a generalised view of central Chilean prehistory, however, while highlighting the bigger picture, it tends to exclude smaller scale cultural developments and localised variations (see Falabella et al. 2013). The archaeological chronology in this sub-chapter is presented in accordance with the current general understanding of central Chilean relative dates and cultural associations. All dates for time periods (e.g. The Archaic Period), are approximate dates based off multiple sources (see Cornejo and Sanhueza 2003; Falabella et al. 2007, Falabella et al. 2013; Galarce and Santander 2011; Planella and Tagle 2004; Planella et al. 2005; Planella et al. 2014; Sanhueza and Falabella 2010), allowing for flexibility in the general timeline. These relative dates are a foundation to work from, rather than a definitive timeline and should be used with that in mind. This sub-chapter will focus primarily on central Chilean chronologies and attempt to break down and discuss the relative and chronometric dates associated with the material evidence from central Chilean archaeological sites.

Relative Chronology and Assigned Cultural Phases for Central Chile

Overview

The relative chronology for Holocene central Chile is commonly split up into six sections, excluding historical times (Table 3.2). The Archaic Period is usually associated with highly mobile hunters and gatherers, while the Early Ceramic Period is predominantly associated with populations that had a mixed subsistence strategy incorporating both hunting and gathering with the addition of sedentism and horticultural practices (Sanhueza and Falabella 2010:127). However, there has been evidence of cultigens (such as *Chenopodium quinoa*) dated to late Archaic Period sites (see Planella et al. 2005), and groups during the Early Ceramic Period that neither became sedentary, nor adopted agriculture (see Cornejo and Sanhueza 2003). Thus, while the below table will be used as

a rough guideline, it is important to keep in mind that not all the populations in central Chile fit neatly into each of those periods.

Table 3.2 Summary of general chronological periods relevant to central Chile. NB: This chronological table details approximate dates for the time periods in central Chile and was adapted from several sources (see Falabella et al. 2007; Galarce and Santander 2011; Planella and Tagle 2004; Sanhueza and Falabella 2010).

CAI = Comunidades Alfareras Iniciales (Initial ceramic communities)

PAT = Período Alfarero Temprano (Early Ceramic Period)

Time Period (BP)	Period	Context
c. 10,000–8000	Early Archaic	Hunter-gatherers
c. 8000-6000	Middle Archaic	Hunter-gatherers
c. 6000-2200	Late Archaic	Hunter-gatherers
c. 2200-1000	Early Ceramic (PAT)	Initial Ceramic (CAI): c. 2200–1750 Bato: c. 1750–1000 Llolleo: c. 1550–1000
c. 1000–600	Late Intermediate	Aconcagua
c. 600–400	Late	Inka

Early to Late Archaic Periods — Hunter-Gatherers (c. 10,000-2200 BP)

The early to late Archaic Periods for central Chile are generally characterised by highly mobile groups of pre-ceramic hunters and gatherers (see Falabella and Stehberg 1989; Sanhueza and Falabella 2010:128). Populations living during this time were thought to be transitional, with evidence for varying degrees of sedentism and the introduction of agriculture and technological proliferation (in the form of various projectile points and food processing tools) (see Falabella et al. 2007). According to the current status of studies conducted on central Chilean sites, there are no "cultural phases" associated with pre-ceramic sites, with its populations being referred to as 'Archaic hunters and gatherers' throughout the literature (see Falabella et al. 2007; Planella 2005; Planella and Falabella 1987; Planella and Tagle 2004). Archaic Period evidence (both archaeological and isotopic) at coastal sites such as Laguna El Peral-C, (LEP-C) in central Chile, indicates that populations were consuming predominantly terrestrial resources with a minor contribution of marine protein to the diet (see Sanhueza and Falabella 2010).
Furthermore, there is no record of specialised technology (i.e., fishhooks and sinkers) for the exploitation of marine resources at coastal central Chilean sites during the Archaic Period (Sanhueza and Falabella 2010:131).

Early Ceramic Period (c. 2200–1000 BP)

The Early Ceramic Period is so named due to the introduction of ceramic wares to central Chilean populations during this time. Ceramic typologies are used during this period to identify different cultural phases/traditions (see Falabella and Planella 1979, 1980, 1982; Planella and Falabella 1987; Sanhueza 2013; Sanhueza and Falabella 2010:128). The beginning of the Early Ceramic Period is known as the Comunidades Alfareras Iniciales (CAI), or initial ceramic communities (Sanhueza and Falabella 2010). During this period (c. 2200–1750 BP), there is a transition from Archaic Period communities, whose primary means of subsistence was hunting and gathering, to communities involved in the production of ceramics, with the addition of some horticultural practices evidenced through the presence of quinoa (*Chenopodium quinoa*). From this initial period, mobile groups, such as the Bato cultural groups appeared, which in turn led to progressively more sedentary peoples, such as the Llolleo cultural groups (Falabella et al. 2007:8).

The Bato Cultural Complex

While the Bato society incorporated cultural elements from the initial ceramic communities, they also created their own stylistic features, which can be seen on ceramic artefacts (Sanhueza 2013). Planella and Falabella (1987) analysed certain attributes and features of pottery from central Chilean sites from the Early Ceramic Period and identified a series of features that are believed to be part of the Bato Cultural Complex. However, it is relevant to note that the Bato Cultural Complex is sometimes referred to as a 'cultural tradition', as it is more commonly defined by what it is not (i.e., through comparison with Llolleo features), rather than what it is characterised by (Sanhueza 2013:28). Features commonly associated with the Bato Cultural Tradition are the presence of dotted lines, linear incisions, oligisto iron (red iron colouring) and negative painting on ceramics (Planella and Falabella 1987:94; Sanhueza 2013). Additionally, Bato pottery encompasses animal and anthropomorphic forms with 'bridge' or 'strap' handles (Figure 3.8). Sites containing this pottery type are all thought to be distinctive, with differences generally relating more to the frequency of certain features, rather than the

type of features (Planella and Falabella 1987:94). Therefore, the Bato Cultural Tradition is largely characterised by the recurring presence of particular elements and the lack of Llolleo Complex features.



Figure 3.8 An example of a Bato anthropomorphic strap-handle pitcher. Image courtesy of the Museo Chileno de Arte PreColumbino.

The Bato cultural group has been recognised as a transitional group, as lithic evidence from sites identified with Bato pottery still reflect traditional hunting and gathering practices, despite the introduction, production and use of ceramics at their sites (Falabella at al. 2007:7). The Bato cultural group was a distinct group of highly mobile people, who exploited different environments (both inland and coastal), throughout central Chile (Falabella et al. 2007:8).

The Llolleo Cultural Phase

In contrast to the more mobile Bato cultural group, the contemporaneous Llolleo cultural group has been characterised as using mixed subsistence techniques, with the combination of hunting and gathering (terrestrial resources and wild vegetables), as well as the introduction of incipient horticulture in the form of the domestication of quinoa (*Chenopodium quinoa*), and the exploitation of both marine and coastal lagoon resources (see Falabella et al. 2007:8; Planella 2005; Planella and Falabella 1987; Planella and Tagle

2004; Planella et al. 2011; Sanhueza 2013). Llolleo Cultural Complex pottery is primarily characterised by monochrome ceramics, plant and zoomorphic decorations with red paint and negative oligisto iron (Sanhueza 2013:30) (Figure 3.9).



Figure 3.9 An example of a Llolleo "Duck-shaped" pitcher. Image courtesy of the Museo Chileno de Arte PreColumbino.

Despite being contemporary with the Bato cultural group, isotopic evidence found from both human and animal values in coastal Llolleo cultural groups demonstrated a higher consumption of C_4 related plants (such as maize) between the populations (Falabella et al. 2007:18). This contrasts with the coastal Bato groups, which were found to be consuming more marine resources at the time (Falabella et al. 2007:18). Furthermore, Llolleo groups were also different in that they were believed to be more sedentary than Bato groups, with Early Ceramic Period archaeological evidence from sites such as LEP-C pointing to a more sedentary lifestyle (Falabella and Planella 1979; Sanhueza and Falabella 2010:131). However, at the Fénix Archaeological Complex ceramic evidence was mainly found relating to the Bato Cultural Complex, with a minor presence of Aconcagua pottery (Galarce and Santander 2011:43). Neither the artefact catalogue nor site report indicates any items relating to the Llolleo Cultural Complex (see Galarce and Santander 2011).

Late Intermediate Period — Aconcagua Cultural Phase (c. 1000-550 BP)

The Late Intermediate Period heralds the appearance of the Aconcagua cultural phase. This phase was made distinctive by the presence of large ceramic containers, believed to be used to store grain from crops (Falabella et al. 2007:19). Aconcagua pottery is also characterised by coffee coloured pots and pitchers, as well as bowls with elaborate black designs over an orange clay background (Falabella 2000; Falabella et al. 2007:19; Sanhueza 2013) (Figure 3.10). From this evidence, and other archaeobotanical evidence, such as the presence of seeds from domesticated plant species, it was thought that the Aconcagua diet was based on hunting and gathering supplemented by horticultural practices (see Falabella et al. 2007; Hermosilla et al. 2003; Massone et al. 1998; Planella and Stehberg 1997).



Figure 3.10 An example of Aconcagua style pottery. Image courtesy of the Museo Chileno de Arte PreColumbino.

In central Chile, ceramic evidence from Aconcagua groups has been found in both inland valley sites, as well as along the coast (Falabella et al. 2007:19). It is further believed that, as well as there being permanent Aconcagua settlements along the coast, that there were seasonal camps that moved from the coastal sites to the inland valleys of the coastal mountain range (*Cordillera de Costa*) (see Falabella et al. 2007; Hermosilla et al. 2003; Massone et al. 1998; Planella and Stehberg 1997). Baseline isotopic values from central Chile may be able to offer comparable data for any isotopic values obtained from skeletal

material for Aconcagua populations. However, archaeological evidence (in the form of ceramic wares), indicates that the Aconcagua presence at the Fénix Archaeological Complex was very minor (Galarce and Santander 2011:43).

Late Period — Inka Cultural Period (c. 550-400 BP)

The Late Period (c. 550–400 BP) marks the end of the Aconcagua phase, the introduction of Inka polities into Chile, and the final period of prehistory before the arrival of the Spanish in 418 BP (1532 AD). While it is beyond the scope of this research to fully discuss the rise, consolidation and 'collapse' of the Inka Empire, this sub-section contains a brief overview of the Inka culture during the Late Period.

The Inka territory, otherwise known as the Tawantinsuyu (meaning 'the state of four corners') refers to the four regions of expansion within the Empire (see Sánchez 2004). These four regions are the Chinchaysuyu, the Antisuyu, the Cuntisuyu, and the Collasuyu, which stretches down into central Chile (see Sánchez 2004) (Figure 3.11).



Figure 3.11 Map showing the location of Tawantinsuyu in South America. Map adapted from Bland (2017), Covey (2008), D'Altroy (2007) and Menzal (1959).

The Inka Empire was a vast polity, which incorporated diverse cultural and political groups across an area that spans large sections of modern day Ecuador, Peru, Bolivia, Argentina and Chile (see Planella et al. 2014; Santoro et al. 2004). The Inka maintained their rule over their vast empire by the establishment of an extensive road system (*qhapaq ñan*) that covered approximately 25,000 km, connecting Cuzco, the Inka capital, to administrative centres in the rest of the Empire (see Alconini and Malpas 2010; Carter and Santoro 2008; Hayashida 1998; Hyslop 1990; Romero 2002). The Inka Empire was distinctive due to its cultural, political, economic, architectural and technological innovations (Planella et al. 2014:511; Sánchez 2004; Santoro et al. 2010). The central part of the Inka Empire was under direct Inka rule, however Inka control/influence varied throughout the Empire, with a lack of architectural features in Chilean coastal valleys

believed to be an indication of less structured control (see Sánchez 2004; Santoro et al. 2010).

The Inka state invested heavily in economic intensification, as evidenced by highly visible storage facilities (for maize and other cultivated crops) (see LeVine 1992; Murra 1980; Rossen et al. 2010; Snead 1992). During Inka rule, intensification of maize agriculture is evidenced by macrobotanical remains, maize storage sheds (*qollqa*) and ceramics, and the presence of irrigation canals and terraces (see Covey 2008; D'Altroy and Schrieber 2004; Dillehay 1977; Farrington 1983). The significance of maize to the Inka empire is recorded in historical records, where it was believed that the cultural status of corn was expressed through its capacity to recreate the emergence myth of Inka society (see Urton 1990) and by extension legitimise the Inka domain (see Bauer 1996; Hastorf and Johannessen 1993; Planella et al. 2014:511). Additionally, maize was associated with public rituals, where the drinking of *chicha* (maize beer) resulted in a substantial increase in maize consumption by men (see Bray 2003; D'Altroy 2001).

Inka towns and administrative centres usually consisted of a large open plaza area with an *usnu* (central platform), as well as principal avenues and access-ways (Covey 2008:818; Hyslop 1990; Morris 2004; Morris and Covey 2003). The sites also consisted of 'essential architecture' such as administrative and elite residential compounds, storage facilities for maize, a Sun temple, and an *aqllawasi* (an Inka nunnery) (see Morris and Covey 2003).

In the absence of Inka architecture, crafts such as ceramics, textiles and metallurgy are used to identify Inka cultural influence (see Hayashida 1998). Inka ceramics are stylistically distinct, with standardised form, geometric designs and polychrome slips (see Bray 2003; D'Altroy 2007; Hyslop 1979). However, while Inka ceramics had a standardised morphology and design, there were local variations throughout the Empire (see Conrad 1977; Covey 2008; D'Altroy 2001) (Figure 3.12).



Figure 3.12 An example of Inka style ceramics. A *maka* (narrow-necked jug), was usually used to transport *chicha* (a fermented corn beverage) in the Inka Empire. Image courtesy of the Museo Chileno de Arte PreColumbino.

The end of Inka expansion by the 420 BP (AD 1530) is believed to be due to various factors (see Carter 2016; Covey 2008; D'Altroy 2007). A combination of factors, such as imperial succession and the Inka civil war (AD 1525–1532), spread of diseases from Spanish contact in Mesoamerica, and superior war tactics by the European invasion (AD 1532), all contributed to the breakdown of the Inka Empire (see Covey 2008:816; D'Altroy 2007). While, no one of these variables may have brought down the Empire exclusively, they all contributed to the end of Inka domination heralded by the 'collapse' of the Inka capital, Cuzco, in AD 1536. Though Spanish colonisation officially occurred in AD 1541, archaeological evidence, from sites throughout South America, suggests that the indigenous inhabitants maintained some of their cultural traditions for decades after the arrival of the Spanish (see Carter 2016:89; D'Altroy 2007; Galdames 1941; Rafino et al. 1997).

Chronometric Dating for Central Chile

Overview

Over the last two decades chronometric dating methods have been applied to previously excavated material from sites in central Chile, further clarifying and refining chronologies based on regional ceramic typologies (see Avalos and Saunier 2011; Falabella 2000; Falabella and Planella 1980; Planella et al. 1991; Rivas and González 2008; Sanhueza 2013; Sanhueza et al. 2003; Sanhueza and Falabella 2010) (Table 3.3). Thermoluminescence (TL) and radiocarbon dating (¹⁴C) have been applied to materials at sites featuring the Bato, Llolleo, Aconcagua and Incan cultural phases, providing date-ranges and allowing an improved chronological resolution for central Chilean archaeological sites. The Fénix Archaeological Complex has the advantage of having 11 radiocarbon dates (on both human skeletal and associated materials) to complement the relative dating (via pottery seriation) at the site. These chronometric dates aid in giving context to the archaeology at the site and provide a more reliable timeframe for the continuities and changes seen in both the archaeological and isotopic data.

Table 3.3 Summary of the chronometric dating conducted at sites in central Chile relevant to this project. Table adapted from multiple sources (see Cornejo and Sanhueza 2003; Falabella et al. 2007; Sanhueza and Falabella et al. 2010). HG = Hunter-gatherers. CAI = Comunidades Alfareras Iniciales (Initial ceramic communities). PAT = Período Alfarero Temprano (Early Ceramic Period). ¹⁴C= Radiocarbon. TL= Thermoluminescence.

Site	Region	Context	No.	Reference ID	Date
Las Brisas 10-14	Coast	Aconcagua	5	Ciprés Consultores	¹⁴ C 1297–1699 cal AD
				2003	
Las Brisas 10-14	Coast	Aconcagua	7	Ciprés Consultores	¹⁴ C 1295–1526 cal AD
				2003	
Laguna El Peral-C	Coast	Llolleo	17	Falabella and	TL 590±140 AD
(LEP-C)				Planella 1991	
Cancha de Golf No 1	Coast	Bato	5	AA63823	¹⁴ C 550–690 cal AD
Tejas Verdes 4	Coast	Llolleo	1	AA64988	¹⁴ C 890–1020 cal AD
Valle Verde	Valley	CAI	6	Beta-213488	¹⁴ C 370–110 cal BC
Valle Verde	Valley	CAI	9	Beta-211328	¹⁴ C 390–180 cal BC
Lenka Franulic	Valley	CAI	1	AA63824	¹⁴ C 170 BC-130 cal AD
El Mercurio	Valley	Llolleo	13	Falabella 2000	TL 1080±90 AD
El Mercurio	Valley	Llolleo	20	Falabella 2000	TL 935±100 AD
Las Pataguas	Valley	Llolleo	2	UCTL-1710	TL 885±80 AD
Lonqúen	Valley	Llolleo	3	AA68048	¹⁴ C 784–1025 cal AD
Country Club	Valley	Llolleo	1	AA68049	¹⁴ C 719–983 cal AD

Paso Agrícola	Valley	Bato (?)	3	AA64986	¹⁴ C 660–900 cal AD
Hospital 8-9	Valley	Bato	1	AA68050	¹⁴ C 575–766 cal AD
Las Mercedes	Valley	Aconcagua	2	AA64987	¹⁴ C 1290–1410 cal AD
Linea 5 Metro	Valley	Inca	5	Reyes 2003	TL 1495±50 AD
					TL 1405±60 AD
Linea 5 Metro	Valley	Inca	4	Reyes 2003	TL 1470±50 AD
					TL 1485±55 AD
Linea 5 Metro	Valley	Inca	1	Reyes 2003	TL 1485±55 AD
Linea 5 Metro	Valley	Inca	3	Reyes 2003	TL 1475±50 AD
El Amendral	Valley	Aconcagua	1	AA68047	¹⁴ C 1328–1615 cal AD
Valle Chicauma	Valley	Aconcagua	1	Sánchez 1995	¹⁴ C 1415–1440 cal AD
Valle Chicauma	Valley	Aconcagua	1	Sánchez 1995	TL 975±100 AD
Las Morrenas 1	Highlands	HG	1	Beta-127529	¹⁴ C 1450–1260 BC
Las Morrenas 1	Highlands	HG	1	Beta-127528	¹⁴ C 1725–1500 BC
La Batea 1	Highlands	HG	1	Beta-32627	¹⁴ C 2930–2610 BC
La Batea 1	Highlands	HG	1	Beta-27504	¹⁴ C 810–165 BC
La Batea 1	Highlands	PAT	1	Beta-26376	¹⁴ C 60–1035 AD
La Batea 1	Highlands	PAT	1	Beta-27503	¹⁴ C 245–655 AD
Los Panales	Highlands	РАТ	1	UCTL-693	TL 765±100 AD
Los Panales	Highlands	PAT	1	UCTL-694	TL 645±100 AD
El Manzano 1	Highlands	PAT	1	UCTL-746	TL 670±130 AD
El Manzano 1	Highlands	PAT	1	UCTL-747	TL 715±100 AD
El Manzano 2	Highlands	PAT	1	UCTL-1217	TL 490±150 AD
El Manzano 2	Highlands	PAT	1	UCTL-1123	TL 795±120 AD
Claros del Bosque	Highlands	PAT	1	UCTL-789	TL930±100 AD
Los Hornos	Highlands	HG	1	-	¹⁴ C 2620–2440 cal BC
Queltehues	Highlands	HG	1	-	¹⁴ C 5255–4785 BC
La Paloma	Highlands	HG	1	-	¹⁴ C 1425–1190 BC

Summary

The relative chronology for central Chilean archaeological sites is separated into five periods that are specific to central Chile and should not be applied to northern or southern Chilean regions. Within these periods are the Archaic hunter-gatherers, early ceramic communities (such as the Bato and Llolleo) and Late Period Aconcagua communities.

Archaeological and palaeobotanical evidence at central Chilean sites have examined diet and landscape use, with results so far indicating that Archaic Period populations were predominantly highly mobile hunter-gatherers (see Falabella et al. 2007; Falabella and Stehberg 1989; Planella 2005; Planella and Falabella 1987; Planella and Tagle 2004; Sanhueza and Falabella 2010). During this time, terrestrial resources (based on plants with the C_3 photosynthetic pathway) were the dominant food source, with the incorporation of some marine foods (Sanhueza and Falabella 2010). Following the Archaic Period, the Early Ceramic Period encompasses the contemporary Bato and Bianca Waldie 160 Llolleo cultural phases and saw the introduction of cultigens, such as domesticated quinoa (*Chenopodium quinoa*) and maize (*Zea mays*) to mobile hunter-gatherer populations (Falabella et al. 2007; Planella and Falabella 1987; Planella and Stehberg 1997; Sanhueza 2013).

Finally, the Late Intermediate Period, heralded the Aconcagua cultural phase and saw the introduction of agriculture, with a mixed marine and terrestrial diet, and the beginnings of sedentism at several sites in central Chile (Falabella et al. 2007; Hermosilla et al. 2003; Massone et al. 1998; Planella and Stehberg 1997). However, ceramic evidence found at the Fénix Archaeological Complex is mostly indicative of the Bato group, with a minor Aconcagua presence and no Llolleo influence noted (see Galarce and Santander 2011). Additionally, chronometric dating for other central Chilean sites provides baseline comparative dates for the Fénix Archaeological Complex. These dates will be compared with the 11 radiocarbon dates discussed in the next section, providing an improved chronological resolution for central Chilean archaeological sites.

The Study Area and Skeletal Collection

Background: The Fénix Archaeological Complex, Quintero Bay

This research project is focused on four archaeological sites belonging to the Fénix Archaeological Complex located in the Bay of Quintero, Valparaíso Region of central Chile. The Fénix Archaeological Complex contains six archaeological sites known as Fénix 2, Fénix 3, Fénix 4, Fénix 7, Fénix 8 and Fénix 12. Three of the sites included in this research project (Fénix 2, Fénix 3 and Fénix 8) are situated between two lagoons (Las Petras and Poniente), with other archaeological sites such as Fénix 4 located between these sites, and Fénix 7 located to the south. Further, Fénix 12 is located approximately 2 km south of the other sites, at the end of a runway (Figure 3.13). According to Galarce and Santander (2011:8) these archaeological sites are situated in an important settlement area of mixed environments, associated with marine terrace systems and relict lakes, which created combined access to coastal resources and permanent lagoon and forest systems. These favourable conditions can be found all along the coast of central Chile (see Carmona et al. 2001; Falabella et al. 2007; Falabella and Planella 1991; Sanhueza and Falabella 2010), which allows a comparison of resource and landscape use at coastal central Chilean sites.



Figure 3.13 Satellite image of the Fénix Archaeological Complex at Quintero, Valparaíso region of Chile. Image courtesy of Google Maps.

The Fénix sites were excavated in the months of January, February, July, August and September 2011 by Chilean archaeologist Patricio Galarce and a team of archaeologists, students and labourers (Galarce and Santander 2011:4) (Figure 3.14). Excavation at the sites consisted of 2x2 m areas dug in spits according to natural stratigraphic units combined with 10 cm vertical control units. Soil was then sieved and sorted according to material type and sent to the laboratory for analysis (Galarce and Santander 2011:3). Galarce and Santander (2011:45) noted that 'complex stratigraphic deposits with significant formational history and contextual associations' were found throughout the site, reflecting a blending of domestic and funerary areas. The excavations were carried out to salvage the archaeological remains due to construction at the site (Galarce and Santander 2011:17).



Figure 3.14 Detailed site drawing of the Fénix sites (excluding Fénix 12) in relation to the lagoons (Las Petras and Poniente) and surrounding area, before the construction of the runway. Drawing adapted from Galarce and Santander (2011).

The construction at the site featured the laying of an airstrip on a military base, where an area of approximately 10,000 square metres was to be disturbed (Galarce and Santander 2011:17) (Figure 3.15). The prehistoric occupation at the sites spans approximately 6000 years (c. 7000–600 BP) (Galarce and Santander 2011) and sits between the middle Archaic (c. 8000–6000 BP) and the Late Intermediate Periods (c. 1000–600 BP).



Figure 3.15 Modern day (2014) area of Fénix sites (facing NE), showing the airstrip development. Author's photo.

Fenix Archaeological Complex Dating

Relative Dating

The sites were relatively dated according to stratigraphy and by seriation of associated materials (ceramics) within each area (e.g., Fénix 3) (Galarce and Santander 2011:43) (Table 3.4). Ceramic styles at the sites predominantly reflected features of the Bato Complex, with the presence of some Aconcagua pottery (Galarce and Santander 2011:44). Furthermore, in general, a lack of ceramics in a stratigraphic layer was thought to be representative of the pre-ceramic middle Archaic to the Early Ceramic Period (c. 8000–2200 BP) (Galarce and Santander 2011).

		D 1 1	
Site	Relative Date	Period	Context
Fénix 2	c. 2200–1000 BP	Early Ceramic	Bato
Fénix 3	c. 7000–700 BP	Mid-late Archaic	Hunter-gatherers
		Early Ceramic	Bato
		Late Intermediate	Aconcagua
Fénix 8	c. 2200–1000 BP	Early Ceramic	Bato
Fénix 12	c. 2200-1000 BP	Early Ceramic	Bato

Table 3.4 Relative dating for the Fénix Archaeological Complex.

Chronometric Dating

Overall, there were five radiocarbon dates conducted on associated material from the Fénix Archaeological Complex (Table 3.5). Three of these dates (Beta-328356, Beta-328357 and Beta-328358) were obtained from marine shell at the sites of Fénix 3 and Fénix 8, in 2012, by Patricio Galarce through Beta Analytic Inc. A further two radiocarbon dates (Beta-419134 and Beta-419135) on marine shell were attained in 2015 by Patricio Galarce through Beta Analytic Inc.

Site	ID	Material	Context	Date (cal)
Fénix 3	Beta-328356	Shell	Middle Archaic:	5170-4740 BC
			Hunter-gatherers	(7120-6700 BP)
Fénix 3	Beta-328357	Shell	Late Archaic:	3730-3360 BC
			Hunter-gatherers	(5680-5320 BP)
Fénix 8	Beta-328358	Shell	Early Ceramic	580-890 AD
			Period: Bato	(1370-1060 BP)
Fénix 3	Beta-419134	Shell	Early Ceramic	825-574 BC
			Period: Bato	(2775-2525 BP)
Fénix 3	Beta-419135	Shell	Late Archaic:	3275-2885 BC
			Hunter-gatherers	(5225-4835 BP)

Table 3.5 Radiocarbon dating for the Fénix Archaeological Complex (see Hood 2012).

Archaeology

Material remains excavated throughout the site belonged predominantly to the Early Ceramic Period (c. 2200–1000 BP), with only shell fragments associated with the middle Archaic Period (c. 8000–2200 BP) (see Galarce and Santander 2011). Artefacts recovered during the Early Ceramic Period excavations consisted of predominantly ceramic, lithic and faunal remains (Galarce and Santander 2011:43). Lithic analysis revealed that people preferred using pebble cores to manufacture stone artefacts primarily made from local raw materials, such as milky quartz (Galarce and Santander 2011:43).

Excavations at the Fénix sites further uncovered a number of marine faunal remains including many types of invertebrates, such as clams (*Mesodesma donacium*), mussels (*Choromytilus chorus*), sea snails (*Tegula atra* and *Concholepas concholepas*), sea urchins (*Loxechinus* sp.) and chitons (*Chiton magnificus*); fish, such as the Pacific jack mackerel (*Trachurus symmetricus*), and the Chilean croaker (*Cilus gilberti*); and sea lions (*Otaria* sp.) (Galarce and Santander 2011:44). A significant number of marine birds, such as cormorants (*Phalacrocorax* sp.) and penguins (*Spheniscus* sp.) were also among the faunal remains at the complex (Galarce and Santander 2011:44).

Bianca Waldie

Remains of terrestrial fauna are predominantly represented by minor species typical of forest and lagoon environments, such as rodents (*Myocaster coipus*) and frogs (*Caudiverbera caudiverbera*) (Galarce and Santander 2011:44). However, there is faunal evidence of camelid remains (*Lama guanicoe*) at the complex, though this species is thought to have had only a minor influence on diets, with ethno-historical records indicating that these animals were not locally obtained (see Galarce and Santander 2011).

In general, faunal remains found in the archaeological excavations at these sites are thought to be evidence of a diet consisting predominantly of marine foods with the incorporation of some terrestrial and lacustrine resources (Galarce and Santander 2011). Floral (pollen) remains found at the sites include the presence of hydrophilic forest and aquatic vegetation, such as the coquito palm (*Jubaea chilensis*) and the peumo (*Cryptocarya alba*) (Galarce and Santander 2011:7). The forest and lagoon areas produce most of the plant species in the area, including plants such as petra (*Myrceugenia exsucca*), boldo (*Peumus boldus*), *chequén* (*Luma chequen*) and reeds (*Phragmites australis*) (Galarce and Santander 2011).

Overall, the Fénix Archaeological Complex contains six areas, of which four (Fénix 2, Fénix 3, Fénix 8 and Fénix 12) were excavated in 2011 and further analysed in a laboratory in Santiago. Floral and faunal remains were recovered from each of the sites and represented both marine and terrestrial resources. However, human skeletal material was the dominant material excavated throughout the area, thus leading to the establishment of the Fénix Osteological Collection (see Rebolledo 2011a, 2011b, 2011c, 2012a).

The Skeletal Collection

As noted above, the primary material evidence recovered from the Fénix sites was human skeletal material (Figure 3.16). Once excavated the skeletal collection was photographed, labelled with numbers and contextual information, bagged, boxed and sent to Santiago for further laboratory study (Rebolledo 2012a:6). No bone pieces were restored during this process, as the archaeologists did not want to contaminate the samples in order to allow for future chemical analyses (Rebolledo 2012a:6).



Figure 3.16 Individual 1 (E1) from Fénix 3. Photo courtesy of Rebolledo (2012b).

After the arrival of the skeletal collection to the Santiago laboratory, the materials were cleaned of any loose dirt, measured and analysed using standard physical anthropology methods (see Bruzek 2002; Buckberry and Chamberlain 2002; Buikstra and Ubelaker 1994; Hillson 1996; Lovejoy et al. 1985; Osborne et al. 2004; Rebolledo 2012a:9; Schaefer et al. 2009; Walker 2005; White and Folkens 2005). Following this, a skeletal inventory was created which consisted of an overview of the elements present, a dental inventory, sex, age and broad information on skeletal characteristics such as biology, pathologies and stress markers (Rebolledo 2012a:10). This inventory was a useful tool in the contextualisation of the isotope results obtained from this project.

Skeletal Overview

Overall, 73 skeletal samples (predominantly phalanges) were obtained from the Fénix Osteological Collection to conduct isotope, trace element and radiocarbon analyses for this research project (Table 3.6). While there was a total of 80 skeletons across four of the sites, some skeletons could not be excavated or were not available/appropriate for sampling (see Rebolledo 2012a). Out of the 70 skeletons from the Fénix 3 site, only 64 were sampled for this research project (see Chapter 4). Skeletal samples E52, E62 and

E70 were not sampled as they were not excavated (see Rebolledo 2012a:5), and a skeletal sample for E8 was not obtained due to it not being present among the collection material. Skeletal samples E11 and E54 were also not sampled due to poor preservation and a lack of appropriate skeletal components (non-cancellous bone).

Site	ID	Sex	Age	Representation	Pathologies/traumas/metabolic
Eániu 2	E1	E		Complete	Tibio injuny. Octooria
Fenix 2	E1 E2	Г	19-24	Complete Complete	Tibla Ilijury. Osteosis.
Fenix 2	EZ	1	12-14	Scarcely Represented	-
Fenix 3					Repaired right zygomatic fracture.
	E1	F	10 62	Complete	formula periositius widespread in both
Eánia 2	E1	Г	40-62	Complete	Dentially repaired modial enterior
rellix 5					circular doprossion loft pariotal:
					Angle callus 7th left rib Cyst in right
					knee joint: mild periostitis in right
	F2	м	33-50	Complete	medial tibia
Fénix 3	F3	M	28-56	Semi-complete	-
Fénix 3	15	1•1	20 30	Semi-complete	Osteomyelitis in left femur left tibio
remx 5					and right tibia: periostitis in hilateral
					ischial spine: periostitis widespread
	E4	F	20-36	Complete	in femur and tibia
Fénix 3	E5	F	40-65	Semi-complete	Anaemia
Fénix 3		-			Osteoma right ear: exostosis with
					reduced left ear canal: 3 osteomas
					front near bregma; healed parietal
					trauma. Active periostitis in both
	E6	F	16-23	Complete	tibias.
Fénix 3	E7	Ι	Ι	Incomplete	-
Fénix 3	E9	Ι	14-16	Semi-complete	-
Fénix 3					Bilateral ear osteoma; repaired right
					rib fracture. Osteolysis in left
					maxillary palatal portion and distal
					portion 3rd molars; repaired nasal
	E10	M	18-24	Semi-complete	maxillary infection.
Fénix 3	E12	F	30-45	Complete	Slight right ear osteoma.
Fénix 3	E13	М	I	Semi-complete	Bilateral porotic hyperostosis.
Fénix 3					Two circular depressions near
			22.24		parietal sagittal suture; callus on 2nd
R (1 0	E14	M	23-36	Complete	right rib.
Fénix 3	E15	M	23-30	Complete	Bilateral ear osteoma.
Fenix 3	E16	I	12-13	Complete	Porotic hyperostosis in left orbit.
Fenix 3	E17	1	15-17	Complete	Porotic hyperostosis in right orbit.
Fenix 3	F10		0.1.2		Osteomyelitis in entire shaft of right
E factor 2	E18 E10	I	9 +/- 2m	Semi-complete	radius and uina.
renix 3	E19 E20		4-2m	Scarcely Represented	-
renix 3	E20 E21		3-0	Semi-complete	-
Fenix 3	EZ1 E22	Г М	18-24	Complete	Usteoma left ear.
Fenix 3	EZZ	M	48-67	Complete	-
renix 3	E22	м	10 24	Cooperate J	Repaired fractured left collarbone; 3
1	I EZ 3	111	10-24	scarcely Represented	T TEDAITED IEIT TID TTAUMAS, MIIO.

Table 3.6: Overview of skeletal material. Table adapted from Rebolledo (2011a, 2011b, 2011c,2012a). F = female. M = male. I = indeterminate.

					generalised femur and tibia
					periostitis.
Fénix 3					Slight right ear osteoma. Active
					periostitis in the middle third right
74.0	E24	M	35-60	Complete	fibula shaft.
Fénix 3	E25		35-56	Incomplete	-
Fénix 3	E26	1	>25	Scarcely Represented	-
Fénix 3					Active periostitis in right distal
	507	F	21.25	T 1.	radius and ulna, right tibla shaft;
F (' 0	EZ/	F	21-35	Incomplete	active osteomyelitis in left tibla shaft.
Fénix 3	E28	М	14-15	Complete	Lower hidden spina bifida.
Fenix 3					Advanced periostitis on distal third
					of femur, both ulna shafts, both right
	F20	г	22 (2	Court court late	tibla and fibula (whole bone) with
E (E29	F M	32-62	Semi-complete	Done apposition and inflammation.
Fenix 3	E30	M	33-45	Incomplete	Circular transportion right porists
Fenix 3					Lambdoid outure (mou diameter
	E21	E	10.25	Complete	14.70mm and min 11.25mm)
Eánia 2	E31	Г	10-25	Complete	14.7911111 and 11111 11.2511111).
Fenix 3	E22	т	10.25	Samaaly Donnagontod	Mild Inflammation in public
Eánia 2	E32	1	10-25	scarcely Represented	Symphysis (public tubercie).
reliix 5					and carpus). Active periostitic in the
					middle distal right tibia and fibula
					with hone apposition and
	E33	м	43_73	Semi-complete	inflammation
Fénix 3	E33 F34	F	18-24	Incomplete	Left ear osteoma
Fénix 3	1.5 1	1	10 21	meompiete	Mild generalised periostitis on femur
I CHIX 5	E35	T	>25	Incomplete	tibia and fibula (bilateral)
Fénix 3	E36	I	9–12m	Incomplete	-
Fénix 3		_			Partially repaired lower left rib
	E37	F	25-39	Incomplete	fracture.
Fénix 3	E38	М	25-34	Complete	-
Fénix 3	E39	F	18-29	Semi-complete	-
Fénix 3					Repaired distal right fibula shaft
					fracture. Mild periostitis in right
	E40	Μ	18-29	Incomplete	distal fibula and tibia.
Fénix 3	E41	Μ	15-21	Complete	-
Fénix 3					Bilateral acetabulum periostitis;
					Initial distal splints on both rear and
					medial third femur shaft and both
	E42	М	20-29	Incomplete	tibia.
Fénix 3	E43	М	39-67	Incomplete	-
Fénix 3	E44	F	25-50	Scarcely Represented	-
Fénix 3	E45	М	14-16	Scarcely Represented	-
Fénix 3					Repaired distal right radius fracture.
	TAC		05		Generalised periostitis on right tibia
	E46		>25	Scarcely Represented	and fibula.
Fenix 3	E47	F	18-24	Scarcely Represented	-
Fenix 3	ይ48		>25	Scarcely Represented	INORE ODSERVADIE.
renix 3					initial periositis on left distal
					anterior lemur and medial shaft of
	E40	Г	25 40	Complete	orbit Spondylolygig in L4 of gring
Fániv 2	549 F50	Г I	33-49 A_5	Semi-complete	Rilateral porotic hyperostesis
Féniv 2	630	1	+-5	Jenn-complete	Mild pariostitic on upper shaft and
I CIIIX D				-	
	E51	F	40-52	Complete	moderate on lower shaft
Fénix 3	E51 E53	F I	40-52 I	Complete Incomplete	moderate on lower shaft.

		1			
Fénix 3					Repaired skull trauma - sagittal
					suture, posterior third, with
					obliteration of the suture; right ear
	nee		45 60		osteoma. Moderate periostitis on the
	E55	M	45-60	Complete	femur shaft and tibia (bilateral).
Fénix 3	E56		10-12	Complete	Mild infection in left ear canal.
Fénix 3	E57	I	1 +/- 6m	Incomplete	Bilateral porotic hyperostosis.
Fénix 3	E58	I	18-20	Scarcely Represented	Mild periostitis in tibia shaft.
Fénix 3					New bone with low density, irregular
					apposition with inflammation
					observed in long bone diaphysis
					(right humerus, right ulna, both
	DE0		1.6		femurs, proximal tibia and fibula
P (1 0	E59		4-6	Semi-complete	(bilateral).
Fenix 3	E60	M	35-67	Semi-complete	Mild periostitis in femur shaft.
Fénix 3	E61	F	40-60	Complete	Mild periostitis in tibia shaft.
Fénix 3					Increased porosity with loss of bone
					tissue in areas associated with fusion
					of epiphysis of long bones, with
					greater loss of tissue in some areas
					(neck femur, femur diaphysis
					anterior, distal snaft, proximal tibla,
					distal epiphysis of fibulas). Also in
					the lower thoracic and lumbar
	E(2		12 14	Comi comulato	vertebrae and the sternal ends of the
F ándar 2	E03	I	13-14	Semi-complete	FIDS.
Fenix 3	E04	I M	3 + / - 1 m	Incomplete	Mild right porotic hyperostosis.
Fenix 3	E05	IVI	33-58	Semi-complete	A sting a suit stitle in former and tilling
Fenix 3	E66	Б	10.24	Comi complete	Active periostitis in femur and tibla
Fánix 2	E00 E67	Г I	27 11	Incomplete	shans.
Fellix 5	E07	I M	37-44	Complete	- Densing right page fracture
Fellix 3	E00	IVI	20-35	Complete	Trop op op oto cic (cymbilic) in
Fenix 3	E09			Complete	reponematosis (syphilis) in
					abalatan Cumatagag lagiang
					skeleton. Gumatosas legions
					skeleton. Gumatosas legions throughout skeleton, bone apposition
					skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion
					skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion, mild active splints in left tible and
					skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion, mild active splints in left tibia and fibula manubrial porosity in sternum
					skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion, mild active splints in left tibia and fibula, manubrial porosity in sternum and irregular thickening of 9 th right
					skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion, mild active splints in left tibia and fibula, manubrial porosity in sternum and irregular thickening of 9 th right rib. Mild bilateral porotic
		M	42-50		skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion, mild active splints in left tibia and fibula, manubrial porosity in sternum and irregular thickening of 9 th right rib. Mild bilateral porotic hyperostosis
Fénix 8	E1	M	42-50 20-25	Complete	skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion, mild active splints in left tibia and fibula, manubrial porosity in sternum and irregular thickening of 9 th right rib. Mild bilateral porotic hyperostosis.
Fénix 8	<u>E1</u> E2	M F I	42-50 20-25 6-13	Complete Semi-complete	skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion, mild active splints in left tibia and fibula, manubrial porosity in sternum and irregular thickening of 9 th right rib. Mild bilateral porotic hyperostosis. Coxal periostitis.
Fénix 8 Fénix 8 Fénix 8	E1 E2	M F I	42-50 20-25 6-13	Complete Semi-complete	skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion, mild active splints in left tibia and fibula, manubrial porosity in sternum and irregular thickening of 9 th right rib. Mild bilateral porotic hyperostosis. Coxal periostitis. - Femur osteoma, tibia trauma
Fénix 8 Fénix 8 Fénix 8	E1 E2 E3	M F I	42-50 20-25 6-13 30-35	Complete Semi-complete Complete	skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion, mild active splints in left tibia and fibula, manubrial porosity in sternum and irregular thickening of 9 th right rib. Mild bilateral porotic hyperostosis. Coxal periostitis. - Femur osteoma, tibia trauma, symphalangism on foot.
Fénix 8 Fénix 8 Fénix 8 Fénix 8	E1 E2 E3 E4	M F I M	42-50 20-25 6-13 30-35 40-50	Complete Semi-complete Semi-complete	skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion, mild active splints in left tibia and fibula, manubrial porosity in sternum and irregular thickening of 9 th right rib. Mild bilateral porotic hyperostosis. Coxal periostitis. - Femur osteoma, tibia trauma, symphalangism on foot. Tibia periostitis.
Fénix 8 Fénix 8 Fénix 8 Fénix 8 Fénix 8	E1 E2 E3 E4 E5	M F I M I	42-50 20-25 6-13 30-35 40-50 6-7	Complete Semi-complete Complete Semi-complete Incomplete	skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion, mild active splints in left tibia and fibula, manubrial porosity in sternum and irregular thickening of 9 th right rib. Mild bilateral porotic hyperostosis. Coxal periostitis. - Femur osteoma, tibia trauma, symphalangism on foot. Tibia periostitis. Porotic hyperostosis.
Fénix 8 Fénix 8 Fénix 8 Fénix 8 Fénix 8 Fénix 8	E1 E2 E3 E4 E5 E6	M F I M I F	42-50 20-25 6-13 30-35 40-50 6-7 20-25	Complete Semi-complete Complete Semi-complete Incomplete Incomplete	skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion, mild active splints in left tibia and fibula, manubrial porosity in sternum and irregular thickening of 9 th right rib. Mild bilateral porotic hyperostosis. Coxal periostitis. - Femur osteoma, tibia trauma, symphalangism on foot. Tibia periostitis. Porotic hyperostosis. Rib fracture, spina bifida.
Fénix 8 Fénix 8 Fénix 8 Fénix 8 Fénix 8 Fénix 8 Fénix 8 Fénix 12	E1 E2 E3 E4 E5 E6 E1	M F I M I F F F	42-50 20-25 6-13 30-35 40-50 6-7 20-25 30-45	Complete Semi-complete Complete Semi-complete Incomplete Incomplete Complete	skeleton. Gumatosas legions throughout skeleton, bone apposition and lysis of muscle attachments, active infections in anterior portion, mild active splints in left tibia and fibula, manubrial porosity in sternum and irregular thickening of 9 th right rib. Mild bilateral porotic hyperostosis. Coxal periostitis. - Femur osteoma, tibia trauma, symphalangism on foot. Tibia periostitis. Porotic hyperostosis. Rib fracture, spina bifida.

Out of the seven skeletons excavated at the Fénix 8 site, only six were sampled for this project. Skeleton E7 was not sampled for this research due to poor preservation (post-mortem fractures and soil matrix staining), and amount of bone available (Rebolledo 2011c:62). Therefore, a total of 73 human skeletal samples (including Fénix 2, Fénix 3,

Fénix 8 and Fénix 12) were collected and analysed for this project from the Fénix Archaeological Complex (see Chapter 4 for more details).

Skeletal Chronology

Relative dates/time periods were assigned to individual skeletons from the Fénix Archaeological Collection by stratigraphic location (and associated ceramics) and extrapolating temporality at the site (Table 3.7). For the sites of Fénix 2, Fénix 8 and Fénix 12 this presented no problem as stratigraphic profiles were simple and taphonomic processes were at a minimum, allowing a clearer identification of temporal properties. However, due to the multicomponent nature of the Fénix 3 stratigraphy (the stratigraphic and spatial overlap as well as the reoccupation of burial spaces), a similar chronology could not be achieved. At present, the key archaeologists involved with this collection in Chile are undertaking a project in order to extrapolate temporality between areas within the Fénix 3 site, in hopes that this will provide better clarity for the individual skeletal chronologies. For this project, relative dates are based roughly on stratigraphic location, associated artefacts and associated radiocarbon dates.

Site	ID	Relative Date	Context
Fénix 2	E1	c. 2200–1000 BP	Early Ceramic Period
Fénix 2	E2	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E1	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E2	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E3	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E4	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E5	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E6	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E7	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E9	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E10	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E12	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E13	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E14	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E15	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E16	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E17	c. 1000–550 BP	Late Intermediate Period
Fénix 3	E18	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E19	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E20	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E21	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E22	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	F23	c 2200-1000 BP	Farly Ceramic Period

Table 3.7 Relative Cultural Chronology for skeletal material from the Fénix ArchaeologicalCollection.

	T		
Fénix 3	E24	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E25	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E26	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E27	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E28	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E29	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E30	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E31	с. 2200–1000 ВР	Early Ceramic Period
Fénix 3	E32	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E33	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E34	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E35	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E36	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E37	C. 2200–1000 BP	Early Ceramic Period
Fénix 3	E38	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E39	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E40	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E41	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E42	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E43	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E44	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E45	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E46	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E47	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E48	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E49	c. 6000-2200 BP	Middle-late Archaic
Fénix 3	E50	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E51	c. 6000-2200 BP	Middle-late Archaic
Fénix 3	E53	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E55	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E56	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E57	c. 6000-2200 BP	Middle-late Archaic
Fénix 3	E58	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E59	c. 6000-2200 BP	Middle-late Archaic
Fénix 3	E60	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E61	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E63	c. 6000-2200 BP	Middle-late Archaic
Fénix 3	E64	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E65	c. 1000–550 BP	Late Intermediate Period
Fénix 3	E66	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E67	c. 2200–1000 BP	Early Ceramic Period
Fénix 3	E68	c. 6000–2200 BP	Middle-late Archaic
Fénix 3	E69	c. 6000–2200 BP	Middle-late Archaic
Fénix 8	E1	c. 2200–1000 BP	Early Ceramic Period
Fénix 8	E2	c. 2200–1000 BP	Early Ceramic Period
Fénix 8	E3	c. 2200–1000 BP	Early Ceramic Period
Fénix 8	E4	c. 2200–1000 BP	Early Ceramic Period
Fénix 8	E5	c. 2200–1000 BP	Early Ceramic Period
Fénix 8	E6	c. 2200–1000 BP	Early Ceramic Period
Fénix 12	E1	c 2200–1000 BP	Early Ceramic Period
1 0111/1 1/2		5. <u>22</u> 00 1000 DI	Larry ocramic i criou

Sex Determination

Of the 73 skeletons, 21 were female (F), 25 were male (M) and 27 are of an indeterminate sex (I). Morphological features of the hip, skull and jaw were used to determine the sex

of the individual, as per biological standards (see Bruzek 2002; Buckberry and Chamberlain 2002; Buikstra and Ubelaker 1994; Lovejoy et al. 1985; Osborne 2004; Walker 2005; White and Folkens 2005). The Análisis de Restos Bioantropológicos: Fénix 3 (analysis of bioanthropological remains) report states that "it was not possible to estimate the sex of any of the sub-adult individuals" (Rebolledo 2012a:13). In some cases, sex was also not able to be determined due to the condition of the skeleton resulting in missing skeletal elements, and thus a lack of diagnostic morphological features (Rebolledo 2011b:10).

Age Estimation

Overall, there were 51 adults, 19 sub-adults and three individuals of an indeterminate age. Age estimation for individuals was based on the degree of degeneration of the sacroiliac joint, the pubic symphysis and degree of dental wear (Rebolledo 2011b:10). Sub-adult age was identified by the degree of epiphyseal fusion (see Schaefer et al. 2009; Scheuer and Black 2004), and dental eruption and development (see Hillson 1996). Following this, the biological ages obtained for each skeleton were entered into a computer program which weighed them against each other and placed them into a broader age range category (see Rebolledo 2011b:10).

Pathologies, Traumas and Metabolic/Nutritional Conditions

Lastly, out of the 73 individuals, only 16 individuals were recorded as having no osteological indication of pathologies (traumas/infections/malnutrition) (see Rebolledo 2011a, 2011b, 2011c, 2012a). Overall, leg traumas were the most prevalent throughout the population, with the addition of skull, arm, collarbone and rib traumas. Infections within the population included osteomyelitis, osteolysis, periostitis and treponematosis (syphilis), with the most common form of infection being periostitis of the lower limbs. There were also indications of nutritional stress within the population, with many individuals suffering from non-specific stress indicators (such as porotic hyperostosis) related to general dietary deficiencies.

Additionally, there were two cases of spina bifida in the population and one case of spondylolysis, reflecting a hereditary element. Finally, it was noted that there was one

case of trepanation within the population, indicating a possible head trauma for the individual.

Fénix 2

The area of Fénix 2 is located southwest of the larger area of Fénix 3 and to the east of Laguna Poniente. Fénix 2 was excavated in January of 2011, with two skeletons recovered: one complete skeleton (>75% of the skeleton present) and one poorly represented skeleton (<25%) (Rebolledo 2011a:26).

The first skeleton was the complete skeleton of a female juvenile adult, between 19 and 24 years of age (Rebolledo 2011a:18–19). Two pathologies were found on the skeleton, including a tibia injury (periostitis) and an advanced osteoma on the left auditory meatus (Rebolledo 2011a:22). Overall, the skeleton was thought to be in good condition for further analyses.

The second skeleton was poorly represented with many of the bones missing. The skeleton is described as very fragile, with poor preservation due to post-mortem fractures throughout and dark brown staining from the surrounding soil matrix (Rebolledo 2011a:26). Owing to the nature of the material, the sex was unable to be determined. The age of the skeleton was estimated to be between 12 to 14 years. As a consequence of the condition of the skeleton, it was not possible to detect any pathologies or make any further observations (Rebolledo 2011a:30).

Due to the limited number of skeletons obtained from this site, few interpretations can be made. Nevertheless, the ear osteoma may be related to the collection of marine resources, via cold water diving, as has been inferred in past research (see Aufderheide and Rodríguez-Martín 1998; Hutchinson et al. 1997; Kennedy 1986; Okomura et al. 2007; Roberts et al. 2013; Standen et al. 1997).

Fénix 3

Stratigraphy

The area of Fénix 3 is the largest excavated part of the Fénix Archaeological Complex and is the northernmost site. The area was excavated in two phases of work during February and March 2011; the first having a total of 283 units excavated and the second having a total of 89 units excavated (Galarce and Santander 2011:4). In total 1454 m² were excavated, totalling 15% of the area (Galarce and Santander 2011:17). The thickness of the excavated deposits at the site of Fénix 3 range from 30–80 cm, in the northern corner and centre of the area, to 100-220 cm, to the south and west of the area (Rebolledo 2012a:19). Stratigraphic Layer 1 is commonly referred to as a "broader stratigraphic unit integration" in the report, with overlapping layers due to similarities in the soil matrix (grain size, colour and texture) and cultural materials found during excavation (Galarce and Santander 2011:21). However, post-excavation exposure of the stratigraphic profile revealed differences in the stratigraphy, therefore separate areas within this layer are denoted with a dashed line in the stratigraphic profile photos (Galarce and Santander 2011) (Figure 3.17) (Appendix C). As mentioned previously, it is these "broader stratigraphic layers" that make it difficult to determine a reliable chronology for some individual skeletons at this site.



Figure 3.17 Stratigraphic profile (W) of Block 6. Segmented lines mark the significant mixed layers within Stratum 1. Photo courtesy of Galarce and Santander (2011).

Stratigraphic Layer 1 (the first excavated layer) generally contained organic materials, whole and highly fragmented shells, and conchilla (fossils of crustaceans, molluscs etc. preserved in natural calcium). The shell species found across the site in Layer 1 were mussels (*Mytilidae* sp.), clams (*Mesodesma donacium, Siliqua patula* and *Veneridae* sp.), snails (*Tegula atra, Concholepas concholepas* and *Fisurella* sp.), sea urchins (*Loxechinus* sp.) and chitons (*Chiton magnificus*). Layer 1 of the stratigraphic units at the Fénix Archaeological Complex also contained the greatest amount of cultural remains, including ceramics, lithics and osteofaunal remains (see Galarce and Santander 2011). Most funerary contexts were contained on the floor of this layer, or between Layers 1 and 2 (Galarce and Santander 2011:37). Layer 1 has generally been assigned to the Early Ceramic Period (c. 2200–1000 BP) due to the presence of the ceramic materials found throughout.

Layer 2 of the excavations commonly contained both whole and fragmented shell remains, conchilla and organic materials. Lithic, ceramic and osteofaunal remains were also usually present in this layer (see above for species). Funerary contexts are predominantly found in the roof of this layer with associated artefacts (Galarce and Santander 2011:38). This layer was relatively dated to the Early Ceramic Period (c. 2200–1000 BP) due to the presence of ceramic remains (Galarce and Santander 2011). Throughout the northern and central sectors of the site Layer 2 is the bottom layer of the excavations (Galarce and Santander 2011:36).

Layer 3 has been relatively dated to the mid-late Archaic Period (c. 6000–2200 BP) due to the absence of ceramics in these layers (Galarce and Santander 2011). Excavations found that some layers contained shells and organic material, while others did not (Galarce and Santander 2011:36).

Layer 4 was generally a fine sandy layer, containing low levels of organic remains and the presence of some fragmented shells. Very few cultural remains were found in this layer and it was relatively dated to the mid-late Archaic Period due to the absence of ceramic remains (Galarce and Santander 2011:37). However, two funerary contexts (E49 and E69) were present in this layer in the western part of the site (Galarce and Santander

2011:25). Layer 4 is also the bottom layer (paleoduna) of the southern section of the site (Galarce and Santander 2011:36).

In the western part of the site, layer 5 is close to the bottom of the stratigraphic profile, with low organic remains and some shell fragments. It has a very low presence of cultural remains and is generally dated to the mid-late Archaic Period due to the lack of ceramics (Galarce and Santander 2011:37).

Finally, Layer 6 is the bottom-most layer (paleoduna) of any of the excavations at the Fénix Archaeological Complex. It is located on the western side of the site and contains only a few fragmented shells. Layer 6 is relatively dated to the mid-late Archaic Period due to the absence of ceramic material (Galarce and Santander 2011:37).

Fénix 3 is an important settlement area with layered deposits, which offers the potential to define the different occupational components and the ability to correlate stratigraphic events at the site (Rebolledo 2012a:19). Stratigraphic correlation across the area shows that the deposition of occupational material began in the mid-Holocene around the mid-late Archaic Period (c. 6000–2200 BP) in layers 3–5, predominantly in the western and southern areas of the site (Rebolledo 2012a:37). Following this was a further occupational sequence in the late Holocene, during the Early Ceramic Period (c. 2200–1000 BP) in layers 1–2 across the entire area (Rebolledo 2012a:37). There is also an indication of the presence of minor occupations during the Late Intermediate Period (c. 1000–550 BP), though this is not discernible in the stratigraphic profiles evaluated due to overlapping layers in the initial layer (Stratum 1) (Rebolledo 2012a:37) (see Appendix A for stratigraphic profiles).

Funerary Contexts for Fénix 3

Of the 66 skeletal samples from the Fénix 3 area, it was found that there were 47 individuals ranging from young to mature adults (>18 years old), 16 sub-adult individuals (<17 years old) and three individuals of an indeterminate age (Rebolledo 2012a:13). Of the 47 adults, 23 were identified as male, 19 as female and eight were indeterminate. Of the total sample, 23 individuals presented a fully represented skeleton (>75%), 16

individuals were semi-complete (75–50%), 15 individuals incomplete (50–25%) and ten individuals were scarcely represented (<25%) (Rebolledo 2012a:15).

From the 66 individuals excavated and analysed from the Fénix 3 area, eight individuals were found to have auditory exostoses, which is usually indicative of cold water marine activities such as diving for shellfish (see Borrero and Barberena 2006; Kennedy 1986; Rebolledo 2012a:32; Roberts et al. 2013). There were also numerous bone traumas found throughout, including trauma to the cranial vault, trauma to the face, spinal trauma, trauma to the clavicles, ribs, upper and lower limbs and various other bones (Rebolledo 2012a:33). It was further found that 27 out of 66 individuals (41% of the total population) were affected by infectious diseases (such as treponematosis and periostitis) (Rebolledo 2012a:35). Additionally, an analysis of dental enamel showed some growth arrest associated with malnutrition (enamel hypoplasia) within the population, particularly among younger members (Rebolledo 2012a:70). There was also one case of a skeleton exhibiting bone loss density and one case of what is believed to be spina bifida (Rebolledo 2012a:71).

The primary function of Fénix 3 was generally interpreted to be that of a cemetery, or at least related to burial practices, with funerary material remains such as offerings in the form of ceramic vessels, drilled stones, shells, pebbles, projectile points and beaded necklaces, all present throughout the area (Galarce and Santander 2011:45). However, mortuary contexts for the first 48 individuals from the area of Fénix 3 were not recorded during excavation. Consequently, connections between funerary offerings and status or class for those individuals cannot be determined (see Rebolledo 2012a:52).

Nevertheless, there was also a domestic habitation element evidenced in this area by intentionally dug pits scattered between the burials, containing waste deposits (Galarce and Santander 2011:40). Other evidence of domestic activities such as ceramic remains, faunal remains, thatched floors and hearths were also found at the site (Galarce and Santander 2011:43). This spatial complexity, combining both domestic and funerary elements in the same area is thought to be a common feature of the Bato Cultural Complex, and therefore reflective of a Bato cultural presence at the site (see Berdichewsky 1964; Carmona et al. 2001; Galarce and Santander 2011:26; Rodríguez et al. 1991; Sanhueza 2013).

Bianca Waldie

Fénix 8

Fénix 8 is situated directly south of Fénix 2 and east of Fénix 7 (not included in this study). The site was excavated in June 2011 and seven skeletons were recovered (Galarce and Santander 2011:1). Fénix 8 had a total of 31 units excavated (Galarce and Santander 2011:4). In total 122.5 metres square were excavated, totalling 5.1% of the area (Galarce and Santander 2011:4). The site had a multi-layered archaeological deposit, allowing the demonstration of different occupational levels within the area.

The excavations at Fénix 8 consisted of three stratigraphical layers. The first layer had an average thickness of 15–20 cm and was made up of a medium-dark brown soil, with organic content, highly fragmented shell pieces, an abundance of conchilla and fragmented ceramics (Galarce and Santander 2011:11). It is thought that these remains indicate an area of domestic activities (residential), evidenced by the ceramic wares and deposition of waste. This layer was relatively dated to the Early Ceramic Period (c. 2200–1000 BP) (Galarce and Santander 2011:11).

The second stratigraphic layer at the Fénix 8 site consisted of dark brown, loose soil, again with organic content, abundant conchilla and fragmented shells. The layer was of varying thickness (15–80 cm) due to pockets of soil continuing down into the third layer. It was interpreted by Galarce and Santander (2011:11) that these pockets were mainly food waste wells, due to the deposition of waste and ceramic materials found within. Layer two also contained sparsely concentrated human burials, indicating a shared domestic and funerary space (Galarce and Santander 2011:11). This layer was also relatively dated to the Early Ceramic Period (c. 2200–1000 BP) due to the presence ceramics (Galarce and Santander 2011:11).

The third, and bottom (*paleoduna*), layer of the Fénix 8 excavations consisted of a light brown, sandy deposit with limited soil organic matter and no shells. This layer was considered to be prior to the beginning of human occupation at this site due to the absence of cultural remains (Galarce and Santander 2011:11) (see Appendix A for stratigraphic profile).

Of the seven skeletons, it was found that there were four adults and two sub-adults comprising two adult females, two male adults, two sub-adults of indeterminate sex, and

one individual with both indeterminate age and sex (Rebolledo 2011b:68). Again, it was not possible to estimate the sex of any of the sub-adult individuals (Rebolledo 2012a:13). Of the total sample, two individuals presented fully represented skeletons (>75%), two individuals were semi-complete (75–50%), two individuals were incomplete (50–25%) and one individual was underrepresented (<25%) (Rebolledo 2011b:60).

Out of the seven individuals recovered and analysed from the Fénix 8 site, two individuals demonstrated signs of bone traumas (foot, leg and rib fractures) and two individuals demonstrated signs of infectious diseases (periostitis) (Rebolledo 2011b:74). Lastly, there was one case of what appears to be spina bifida in the sacrum of one of the skeletons (E6) (Rebolledo 2011b:75). Finally, out of the seven skeletons recovered, only six were sampled for isotope analyses. Due to the poor condition and representation of one of the skeletons, (E7), it was not sampled for this research.

The occupation sequence at Fénix 8 demonstrates spatial overlap between domestic and funerary activities (Galarce and Santander 2011:16). Domestic activities are inferred due to the presence of garbage pits, hearths, ceramic remains, and stone materials, with the most frequent cultural materials uncovered being highly fragmented ceramic remains, stones, flakes, pebbles and faunal remains (Galarce and Santander 2011:13). Sparsely concentrated human burials are evidence of the funerary practices throughout the area. Therefore, it is believed that, in functional terms, Fénix 8 was a residential settlement with discreet funerary areas (Galarce and Santander 2011:4).

Fénix 12

The site of Fénix 12 is located at the bottom of the airstrip construction, approximately 2 km south of the other Fénix sites. Fénix 12 was excavated in February 2011, with one skeleton recovered (Rebolledo 2011c:3). The skeleton found at this site was found in Layer 1, with associated malacological (mollusc) remains (Rebolledo 2011c:3). The skeleton is considered fully represented (>75%) but is in a fragile condition owing to post-mortem fractures and discolouration from the soil matrix (Rebolledo 2011c:23). The skeleton belongs to an adult female, with an average age range of between 30 and 45 years old (Rebolledo 2011c:17). There were no observed pathologies on the skeleton (Rebolledo 2011c:19).

Based on the skeletal material (one skeleton), an interpretation cannot be established. Likewise, the possibility of establishing a general way of life for this site is limited (Rebolledo 2011c:24). However, this skeleton will be compared to other skeletal material at the Fénix Archaeological Complex.

Summary

Overall, 73 skeletons were analysed for this project from the Fénix Archaeological Complex. Out of these 21 are female, 25 are male and 27 are of an indeterminable sex. The age range of the population ranges from infants to elderly adults (c. 0–70 years old), with 51 adults, 19 sub-adults and three individuals of indeterminate age. There were also a range of pathologies found during the physical anthropological analysis of the skeletons, including bone traumas, infections and metabolic deformities. Past radiocarbon dating conducted on associated marine shell has provided a long chronological sequence of between 7120 and 2525 cal BP for the Fénix Archaeological Complex.

The greatest amount of material in the Fénix Osteological Collection is from the site of Fénix 3. Despite there being less material from the other sites, there is the possibility of establishing the general way of life of these people by integrating the data from all the Fénix sites and conducting a broader analysis of the whole as the Fénix Archaeological Complex. Ultimately, Galarce and Santander (2011:37) note that the Fénix area demonstrates a complex stratigraphy with the integration of domestic and funerary areas, shown through the deposition of large amounts of waste associated with the funerary contexts.

Overview

This chapter summarises the procedures used for this research, including background research, bone sampling and collection, permits, ethics and quarantine procedures, cleaning of lab equipment and isotopic and trace element analyses of the skeletal samples.

Background Research

First, an archival investigation of archaeological research conducted on Chilean coastal archaeology within the Valparaíso region was undertaken. Following this a synthesis of central Chilean isotope archaeology was conducted. This was completed to ensure that there was a comprehensive overview of previous isotopic and archaeological research for the region. Personal contact with a key Chilean archaeologist (and adjunct supervisor), Professor Calogero Santoro, was vital for obtaining this information for the study area. Personal contact with primary archaeologists, Patricio Galarce and Gabriela Santander, also significantly contributed to ensuring a full understanding of the Fénix Osteological Collection, including the methodology and context of the excavations conducted at the Fénix sites.

Bone Sampling and Collection

The material analysed in this study is comprised of the human skeletal material of 73 individuals from the Fénix Osteological Collection. Prior to deciding upon sampling methods, an overall assessment of the skeletal material was completed.

Upon examination, it was found that the collection was in excellent order, with all the contextual data and identification tags intact. A condition of the removal of skeletal material was that there be minimal disturbance to the collection. Only a small amount of material could be sampled from each skeleton, as it was required that the skeletal collection remain intact. It was also agreed, between the principal investigator, the archaeologists and the National Council of Monuments, that for the small amounts taken, plaster moulds would be made of the sampled pieces for future reference. After an initial evaluation of the collection, and in order to adhere to the requirements of sample removal, it was concluded that the elements most appropriate and least problematic to be sampled for isotopic analysis were the phalanges (in this case finger bones).

An effort was made to only select well-preserved skeletal material because it is more likely to contain the collagen levels needed for the analysis (see DeNiro 1985). Material that appeared burned, or chalky was avoided in favour of material that looked more robust. Darker pieces of bone were avoided because in past research (see Petruzzelli 2012) it was found that these samples were usually lost in the demineralisation process. Of the available phalanges, the best visually preserved sample was selected (Figure 4.1). However, where the phalanges were unavailable and/or unsuitable (such as infant phalanges, which didn't contain enough bone mass), the next most appropriate element was selected (e.g., long bone fragments).



Figure 4.1 Photograph of one of the bone samples for research. Author's photo.

Once taken, each sample was cleaned of any superficial contamination (such as dirt or plant matter) with a small brush, photographed, and placed in a plastic bag containing all relevant contextual data for the sample. Contextual data recorded included the store number/site number, tomb/burial number, dates, type of

material, skeletal classification and associated material present. Following the sampling process, the material was boxed and left in the laboratory in Santiago to undergo the above mentioned non-invasive cast-moulding procedure, completed by Chilean archaeologist Gabriela Santander. Following this, and upon receipt of the required permits, the samples were sent to Australia for analysis (see section below).

Permits, Ethics and Quarantine Procedures

Paperwork for this project was lodged with the National Council for Cultural Heritage (Consejo de Monumentos Nacionales) in Chile, so that samples could be taken out of the country for analysis (Appendix A). All requisite paperwork, permits and ethical procedures were handled by archaeologist Patricio Galarce who also obtained the permits for the excavation in 2011 and currently oversees the skeletal collection in Santiago. A letter from the manager of the Flinders University ethics committee indicates that Flinders University did not require any additional ethical procedures in relation to this project (Appendix A).

Skeletal samples were also checked by border security and customs upon entering Australia. The Department of Agriculture, Fisheries and Forestry (DAFF) previously indicated in writing that if the skeletal samples were cleaned of any dirt or contaminants, they did not need to undergo quarantine procedures.

Bone Sample Division

Upon arrival in Australia all the skeletal samples were weighed to record their whole bone weight. Following this, each sample was crushed into large chunks using a mortar and pestle and divided up for analysis. The samples were split into two groups, one to be used for carbon and nitrogen analysis and one to be used for oxygen isotope analysis. However, six of the samples that were to be used for oxygen isotope analysis were used for direct radiocarbon dating, as chronological resolution was prioritised over oxygen isotope analysis. Once the samples were grouped they were then each weighed again prior to chemical preparation work commencing.

Cleaning of Lab Equipment

All laboratory glassware was first cleaned with dilute Pyroneg detergent, to remove any outer organic contaminants. Glassware was then soaked in a 10% dilution hydrochloric (HCl) acid bath for 24 hours. Following this all glassware was rinsed in demineralised water five times and then put into the oven to dry. All other laboratory instruments were cleaned with ethanol and rinsed in demineralised water before and in between uses.

Preparation of Bone for Stable Carbon and Nitrogen Isotope Analysis

Overview

As prehistoric materials may suffer post-mortem contamination by substances that have different stable isotope ratios, they need to be purified before undergoing analysis (Ambrose 1993:71). Bone lipid δ^{13} C values may also be approximately 6–12% more negative than those of the collagen and, therefore, their removal using hydrochloric acid (HCl) is essential (Ambrose 1993:73; DeNiro and Epstein 1978). Further, humic acids have an isotopic composition that reflects the local plant biomass, rather than the diet of the person, and can affect collagen carbon isotope ratios. Consequently, the removal of humic acids using sodium hydroxide (NaOH) is also recommended (Ambrose 1990:432). Most sources of contamination can be largely eliminated with simple mechanical and chemical pre-treatment procedures.

Upon arrival to the Flinders University Archaeology Research Laboratory in Australia, standard preparation procedures were employed as outlined by Anson (1997), Hiebert and Schoeninger (1987), Pate (1995), and Roberts et al. (2013). Chemical preparation of the 73 skeletal samples for stable carbon and nitrogen isotope analysis involved, firstly, cleaning of the bone pieces using a wire brush to remove loose dirt and other external contaminants. Following this, demineralisation of the bone in 2–3% dilute hydrochloric acid (HCl), per the

methods of Sealy (1986), was conducted. Once bone samples were demineralised to a sufficiently spongy consistency, they were then soaked for 24 hours in a 0.125 M solution of sodium hydroxide (NaOH) to remove humic acids and other base-soluble contaminants. All collagen extracts were rinsed thoroughly with deionised water following both chemical treatments to remove the dissolved contaminants. Finally, collagen samples were placed in labelled sample containers and dried in the oven at 40°C for two days, or until completely dry.

The final step of the bone preparation procedure was determining the yield from the whole bone. The yield of the bone equals the final weight of the dry bone sample divided by original weight of the untreated sample and multiplied by 100 (see Ambrose 1990; DeNiro and Weiner 1988; Van Klinken 1999). Collagen yield is used to assess the quality of the bone for isotope analysis (see Pate 1997, 1998). Samples that achieve a yield of between 5–30% are thought to be of an acceptable level. If the yield is below 5%, it indicates degraded collagen and resampling of the whole bone and starting the process again is recommended. If the yield is greater than 30% then the bone needs to be put back into the HCl and demineralised further for analysis (Roberts 1998:61). Samples that achieved 5–30% yield were ground to a fine powder and placed in a desiccator (Figure 4.2). The grinding process was carried out in a mechanical mill with grinding vials and a ball made from agate.


Figure 4.2 Photograph of prepared samples for stable carbon and nitrogen isotope analysis. Author's photo.

Sample demineralisation in HCl took between one and five days. The differing amount of time between sample demineralisation usually depended on the size and density of the bone piece used in the demineralisation process. All sample preparation was undertaken at the Archaeological Research Laboratory, Humanities Building of Flinders University and complied with all OH&S requirements.

Mass Spectrometry

Mass spectrometry is used to determine the masses and abundance of naturally occurring isotopes. The instrument is designed to 'separate charged atoms and molecules on the basis of their masses based on their motions in magnetic fields' (Faure and Mensing 2009:64). Thus, mass spectrometers can measure certain elements in natural materials, allowing for the interpretation of isotopic variations (Faure and Mensing 2009:64). These isotopic variations can be measured in human bone. The variations of carbon and nitrogen isotopes found

in the human bone samples from the Fénix Osteological Collection thus allows for an examination of human diets.

Following the grinding of the collagen extracts in the mechanical mill, the samples were taken to the Mawson Building at Adelaide University and were weighed using a Sartorius Electronic Balance, which is accurate to five decimal places (Figure 4.3). Between 0.3 and 1.3 mg of each powdered sample was placed into individual pure tin capsules to be loaded for mass spectrometry. Pure tin is used as it is designed to have no influence on the mass spectrometer's analytical processes.



Figure 4.3 Photograph of sample weighing at Adelaide University. Author's photo.

Glycine, glutamic acid and triphenylamine (TPA) were used as standards for this analysis. Additionally, a glycine standard from the laboratory of Margaret Schoeninger (The Glenn Black Laboratory of Archaeology at Indiana University) was used to provide comparison. Standards were inserted into the sample tray at various intervals to ensure consistency of results. Carbon and nitrogen elemental concentrations and stable carbon and nitrogen isotope values were determined by Mark Rollog of Adelaide University using a Eurovector EruoEA coupled with a Nu Instruments Horizon CF-IRMS. Duplicates of many of the samples were also submitted for analysis to ensure accuracy. Analytical precision was better than $\pm 0.06\%$ for δ^{13} Ccol and $\pm 0.13\%$ for δ^{15} N. Delta (δ) values were calibrated to multiple international standards (such as IAEA, C6, N1, N2, NO3, USGS32, USGS35, USGS40 and USGS41), with the final values reported being averages of multiple sample analyses. Carbon and nitrogen elemental concentrations were used to calculate atomic C:N ratios.

Collagen contamination for this research was checked by measurement of atomic carbon to nitrogen (C:N) ratios (DeNiro 1985). Atomic C:N ratios are used to ascertain the presence of acceptable collagen in archaeological extracts in relation to stable isotope analysis (DeNiro 1985). The range for stable carbon and nitrogen atomic ratios has been measured by recording the atomic ratio ranges from 415 mammals (see Ambrose 1990; Anson 1997; DeNiro 1985; Pate 1997, 1998) and is acceptable between the values of 2.8 and 3.6. Samples out of this range indicate that the bone collagen has been subject to diagenesis and is therefore, not well preserved and needs to be put through the extraction process again (DeNiro 1985:808). All C:N ratios utilised for this analysis were within the acceptable range of 2.8–3.6.

Dietary Interpretation Methods

Prior research has demonstrated various methods to establish the relative contributions of marine and terrestrial foods to the diets of prehistoric humans. The combined use of stable carbon and nitrogen isotope data provides the best indicator of marine versus terrestrial dietary composition (see Barberena 2002; Borrero and Barberena, 2006; Burger and van der Merwe 1990; Falabella et al. 2008; Finucane et al. 2006; Gil et al. 2006, 2009; Pate and Owen 2014; Tykot and Staller 2002; Walker and DeNiro 1986).

Due to the climatic and environmental conditions in Chile, wild plant species in Chile exclusively follow the C_3 (Calvin-Benson) photosynthetic pathway, with no

wild C₄ (Hatch-Slack) plants being present in Chile. Furthermore, there is no evidence for CAM pathway plants (succulents etc.) being consumed by native Chilean populations (see Falabella et al. 2008). Conversely, on the basis of current data, the C₄ cultigen maize was introduced to the region later in prehistory (c. 1750–1000 BP) and started to appear in the diets of central Chileans during the Early Ceramic Period (c. 2200–1000 BP).

Relative contributions of marine and terrestrial foods were calculated according isotopic "endpoints" method used by multiple authors (see Aufderheide and Santoro 1999; Roberts et al. 2013; Tykot 2004; Tykot et al. 2009). The isotopic "endpoints" method is based on the theory that there are standard isotopic values for 100% C₃ and 100% C₄ plants, which can be matched with the dietary δ^{13} C signals after fractionation. The isotopic "endpoint" employed for 100% C₃ terrestrial plants, such as trees, shrubs and temperate grasses, was -26.5‰ and the endpoint for pure C₃ feeders was -21.5‰ ($\delta^{13}C_{col}$) and -14.5‰ ($\delta^{13}C_{ap}$).

Sub-tropical plants, such as maize, have an isotopic "endpoint" of -12.5‰ for 100% C₄ terrestrial plants. Consequently, pure C₄ feeders have an isotopic endpoint of -7.5‰ ($\delta^{13}C_{col}$) and -0.5‰ ($\delta^{13}C_{ap}$), and humans consuming plants using the C₄ pathway will have more enriched $\delta^{13}C$ values than humans consuming plants using the C₃ photosynthetic pathway. Furthermore, humans and animals consuming a mixed diet will demonstrate intermediate values between those for C₃ and those for C₄ resources (see Ambrose and Norr 1993; Lee-Thorp et al. 1989; Tykot et al. 2009).

Justification of Methods

The methods used to analyse carbon and nitrogen in this research project are universally accepted as appropriate. In a recent article by Sealy et al. (2014) two methods of extracting bone collagen for stable carbon and nitrogen isotope analysis were compared. It was found that there were no statistically significant differences between the method that is used in this project — the older method (see Ambrose 1990; Berger et al. 1964; Chrisholm et al. 1983; Sellstedt et al. 1966) of demineralising whole bone "chunks", compared to the more sophisticated collagen extraction protocols (see Ambrose 1990; Brock et al. 2010; Bronk Ramsey et al. 2004; Longin 2001) being used in some laboratories today (Sealy et al. 2014:64). It was also noted that, while there is no noticeable effect between 0.05 and 2 M acid demineralisation, more dilute acid does lead to a more gradual demineralisation process, which is better suited to smaller and less well-preserved samples (Sealy et al. 2014:65). Lastly, all the mass spectrometry samples were run at the same laboratory at Adelaide University to keep laboratory variations to a minimum. The use of laboratory standards was also undertaken which validated the consistency of the results.

Preparation of Bone for Stable Oxygen Isotope Analysis

Overview

As noted previously, prehistoric materials may suffer from post-mortem contamination by substances with different isotope ratios and need to be chemically purified before undergoing analysis (see Ambrose 1993). Carbon and oxygen isotope ratios in skeletal material can be measured either from the carbonate or phosphate fraction of bone (Buzon et al. 2011:450). While phosphate is less affected by post-burial diagenesis (see Iacumin et al. 1996; Longinelli 1984; Luz et al. 1984; White and Spence 1998), more studies have been known to use carbonate for analysis (see Buzon et al. 2011; Gil et al. 2011; Knudson 2012b; Sponheimer and Lee-Thorp 1999; Turner et al. 2009). The results obtained from the carbonate and phosphate component of the same sample are offset but this effect can be easily corrected (Chenery et al. 2012).

This project analyses carbon apatite ($\delta^{13}C_{ap}$) and oxygen apatite ($\delta^{18}O$) in the bone of 67 individuals from the Fénix Osteological Collection. Out of the original 73 skeletal samples, only 67 were available for $\delta^{13}C_{ap}$ and $\delta^{18}O$ analysis as there was a limited amount of bone available and six of the 73 samples being prioritised for carbon, nitrogen and radiocarbon dating.

Preparation of bone carbonate for carbon and oxygen isotope analysis was conducted at the Mawson Laboratories of Adelaide University under the supervision of analytical chemist Mark Rollog. Samples ranging in weight from 0.5 to 1 mg were first cleaned of any exterior contaminants, such as dirt, using a wire brush. Following this, each sample was soaked in 3% HCl solution for approximately five minutes. Samples were then rinsed three times each in Reverse Osmosis (RO) water and soaked in an 8–12% solution of sodium hypochlorite (NaOCl) solution overnight to eliminate organic contaminants. This method has been previously shown to successfully remove diagenetic contaminants (see Koch et al. 1997).

The NaOCl was then pipetted off and each sample was rinsed three times in RO water. After the RO water was pipetted off, the samples were put into an oven at 40°C overnight, or until completely dry. Once the samples were dry they were manually crushed into a fine powder and put into 4.5 ml Labco Exetainers (Figure 4.4). Once the samples were sealed in the test tubes, they were purged with helium. After purging, 10 drops (~50uL) of phosphoric acid (103–104%) was injected and the samples were left to dissolve overnight at 70°C.



Figure 4.4 Photograph of a stable carbon and oxygen isotope sample tray ready for mass spectrometry. Author's photo.

Mass Spectrometry

The carbon and oxygen isotope composition of hydroxyapatite carbonate was analysed by Mark Rollog of Adelaide University using a Nu Instruments GasPrep in line with a Nu Instruments Horizon continuous flow isotope ration mass spectrometer (CF-IRMS). ANU P3, UAC-1 and IAEA CO-8 were used as standards and inserted into the sample tray at various intervals to ensure consistency of results. Duplicates of many of the samples were also submitted for analysis to ensure accuracy.

Analytical precision was better than 0.12%. Delta (δ) values were corrected to Adelaide University's internal laboratory standards (ANU and UAC), which had previously been calibrated to international standards. Additionally, IAEA CO-8 was added for quality control. Finally, the end values reported were averages of multiple analyses of the same samples.

Justification of Methods

The methods used for carbon and oxygen isotope analysis are standard methods for the procedures being undertaken (see Gil et al. 2011; Tykot 2004). Pretreatment for the skeletal samples was conducted according to the methods of Gil et al. (2011). Analysis was conducted on human bone, as it was the only available material in the collection (with the teeth being reserved for other research). Postmortem degradation is common in bone; therefore, bone carbonate carbon ($\delta^{13}C_{ap}$) and oxygen isotopes were measured due to their ability to be thoroughly cross-referenced with the nitrogen and carbon ($\delta^{13}C_{col}$) values. Oxygen bone carbonate isotope analysis was chosen due to it being relatively fast and cheaper than standard phosphate analysis. Oxygen carbonate is also determined concurrently with $\delta^{13}C_{ap}$, which has the bonus of yielding ecological and dietary information that can be compared with the carbon and nitrogen isotope analysis of the collagen in the bone samples, contributing additional information and accuracy to this study.

Lastly, carbon and oxygen isotopes of skeletal hydroxyapatite were run by the same person in the same laboratory as the previous stable carbon and nitrogen isotope analysis on collagen. The use of laboratory standards was also undertaken to ensure the consistency of the results.

Radiocarbon Dating of Skeletal Samples

Of the 73 skeletal samples in the Fénix Osteological Collection, six samples were chosen for radiocarbon dating (Figure 4.5). The samples were chosen by the principle archaeologist, Patricio Galarce, and myself. Samples were selected according to their stratigraphic location within the Fénix area (oldest/deepest and youngest/shallowest) as well as to double check previous radiocarbon results from associated materials (see Discussion section for more information).



Figure 4.5 Photograph of skeletal samples for radiocarbon dating. Author's photo.

Samples ranging in weight between 0.6 and 1.5 mg were submitted to the Accelerator Mass Spectrometry (AMS) chemistry laboratories at the Australian Nuclear Science and Technology Organisation (ANSTO). Once submitted, all samples underwent initial nitrogen testing. Nitrogen examination was conducted by subjecting a sub-sample of powdered bone to elemental analysis using an

Elementar Vario MICRO Cube elemental analyser, to determine the preservation of the bone for dating before chemical pre-treatment commenced.

Measuring the nitrogen percent (N%) of powdered whole bone allows an estimate of the quality of collagen present before treatment commences and is therefore a preliminary indicator used to gauge bone quality (see Tisnérat-Laborde et al. 2003). According to Tisnérat-Laborde et al. (2003) the quantity of nitrogen usually ranges from approximately 4% wt in fresh bone to below 0.2% wt in poorly preserved bone. It was found that all the bone samples had nitrogen contents of above 0.2% wt, indicating sufficient collagen and good preservation, and were therefore continued through to chemical pre-treatment (Bertuch 2016).

Chemical Preparation

The method that was used by ANSTO to pre-treat the skeletal samples, to remove carbonaceous contamination and yield a reliable radiocarbon result, was the ultrafiltration protocol (Bertuch 2016; Bronk Ramsey et al. 2004; Brown et al. 1988; Higham et al. 2006).

Chemical preparation of the skeletal samples for radiocarbon dating using the ultrafiltration protocol involved, firstly, cleaning of the bone samples using a small drill, washing them in deionised water, freeze drying them and then crushing them.

Following this, samples were subjected to bone quality tests in order to confirm that there was adequate collagen preservation for dating (see Bertuch 2016). Carbon to nitrogen elemental ratios (C:N) for all samples fell within acceptable ranges (2.8–3.6), therefore the collagen was suitable for AMS measurement (Bertuch 2016). Once it was confirmed that all six of the samples had viable quantities of collagen, treatment to extract the gelatin commenced (Bertuch 2016).

Gelatin Extraction

Gelatin was extracted from the bones using a modified Longin (1971) method. The crushed bone was demineralised with 0.5 M HCl, and the organic residue treated

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with 0.1 M NaOH, followed by 0.5 M HCl. The "collagen residue" was then gelatinised by heating in dilute HCl (pH 3) at 75 °C for 20 hours and the solution filtered at 100 μ m. The gelatin solution underwent ultra-filtration at 30kD, and the >30 kD fraction was retained and freeze dried (Brock et al. 2007:187). As mentioned previously, sub-samples of the collagen were taken for elemental analyses (C/N and δ^{13} C) to ensure that the bone was sufficiently preserved, and that humic contamination had been removed.

CO₂ Extraction

After gelatinisation, CO_2 was extracted from the six skeletal samples, alongside CuO and Ag wire, via combustion at 900 °C for 5 hours using the sealed-tube technique (see Vandeputte et al. 1996). Once the collagen had been extracted and quality checked, the samples were further processed to graphite in the AMS chemistry laboratories as per Hua et al. (2001).

Graphitisation

Graphitisation of the samples was achieved by the reduction of carbon dioxide using a Zn (400 °C) and Fe catalyst (600 °C) in the presence of a small amount of H_2 , according to the methods of Hua et al. (2001).

Accelerator Mass Spectrometry

Upon the completion of graphitisation of the samples, the graphite iron mixture was measured by the STAR 2 MV accelerator at the Australian Nuclear Science and Technology Organisation (ANSTO), with all measurements normalised against an oxalic (HOXI) international standard (Bertuch 2016).

Calibration

As conventional radiocarbon dates do not directly equate to calendar years (de Vries 1958; Stuiver and Suess 1966; Reimer et al. 2009, 2013; Taylor 1987), they need to be calibrated. Calibration is essential because conventional radiocarbon dates are calculated on the assumption that the ¹⁴C content of the atmosphere has been constant over time (Bronk Ramsey et al. 2013; Stuiver and Polach 1977),

when in actuality, atmospheric ¹⁴C concentration has varied throughout time (see de Vries 1958). Calibration is a way of correcting the ¹⁴C ages, so that they can be compared against each other, and with records dated by other means such as uranium series, ice-core, tree ring and historical dating (Reimer et al. 2009:1112). In addition, calibrated radiocarbon ages allow the assignment of calendar ages in years BC, BCE or AD.

Dendrochronology, the dating of tree growth rings, has been most commonly used to calibrate radiocarbon dates, as tree rings have carbon incorporated directly from the atmosphere at the time of formation (Reimer et al. 2013:1870). This means that dendrochronologically dated records provide a direct measure of atmospheric ¹⁴C content on an absolute timescale (Reimer et al. 2009:1114). From dendrochronology, amongst other ¹⁴C measurements (of plant macrofossils, corals, speleothems and foraminifera), numerous calibration curves have been constructed (see Klein et al. 1982; Pearson and Stuiver 1986, 1993; Stuiver 1982; Stuiver and Becker 1986,1993; Stuiver et al. 1998). These calibration curves function to compare the uncalibrated radiocarbon dates to known data sets for specific areas (northern hemisphere, southern hemisphere and marine). Through this, a probable date can be obtained, however, it has been noted (see Hogg et al. 2013; Remier et al. 2009, 2013) that different regions of the world provide slightly different dates (from dendrochronology etc.) and therefore, specific regional datasets have been developed (e.g. IntCal, SHCal, Marine).

It has been established that radiocarbon ages of marine samples are several hundred years older than their terrestrial counterparts (see Ingram and Southon 1996; Reimer et al. 2009, 2013; Stuiver et al. 1986; Stuiver and Braziunas 1993). This age difference is due to marine organisms sourcing their carbon from the large carbon reservoir of the oceans, which are depleted of radiocarbon, giving an apparent age older than terrestrial organisms, which source their carbon from the atmosphere (Ingram and Southon 1996:573.). Marine calibrations are estimated against a global marine reservoir curve, which estimates the global marine reservoir effect over the last 50,000 cal years BP (Reimer et al. 2009, 2013; Stuiver and Braziunas 1993; Taylor 1987).

To calculate the marine reservoir curve for a specific location a marine reservoir correction must be made. The regional difference from the average global marine reservoir correction is designated ΔR (Stuiver and Braziunas 1993) and varies with location due to complexities in ocean circulation, such as upwelling, changes in currents and freshwater inflow in coastal regions (Ingram and Southon 1996:573; Stuiver et al. 1986). ΔR is calculated by measuring the difference between ¹⁴C years of known age marine samples and the marine model age for that calendar age (Ingram and Southon 1996:573).

To consider the possible marine reservoir effects resulting from the marine component of the diet, a combination of both terrestrial and marine calibration curves was required to accurately calibrate the dates. The radiocarbon dates for this project were calibrated using Calib 7.0.4 (Stuiver and Reimer 1993), with a mixture of Marine13 (Reimer et al. 2013) and SHCal13 (Hogg et al. 2013) curves to account for this. Marine calibration was based on the fraction of marine carbon determined for each individual by measuring two endpoints, δ^{13} C 20.1 and δ^{13} C 8.7, representing 100% terrestrial and 100% marine diets (Appendix B).

After the percentage of marine carbon was determined, a location-specific reservoir correction of 226±98 years proposed by Ortlieb et al. (2011), for a site approximately 50 kilometres south of Quintero Bay, was used for calibrating the marine curve for these dates to adjust for regional oceanic variation in ¹⁴C (Ingram et al. 1996; Ortlieb et al. 2011; Taylor and Berger 1967).

Justification of Methods

According to Bronk Ramsey et al. (2004), the ultrafiltration method has been shown to remove contamination more effectively than other methods. Ultrafiltration acts to remove material with a molecular weight below 30 kD, which removed contaminants such as salts, fulvic acids and degraded collagen.

Problems encountered with the ultrafiltration method in the past (at Oxford Radiocarbon Accelerator Unit) have been explored in Bronk Ramsey et al. (2004) and Brock et al. (2007) and have been accounted for at the ANSTO AMS chemistry

laboratories. Contamination arising from the use of insufficiently cleaned ultrafilters has been previously noted and therefore routine quality assurance measures are now in place at the ANSTO AMS chemistry laboratories to ensure that the use of ultrafilters does not pose a contamination risk for samples. Several quality assurance tests are performed to make sure all carbonaceous contamination has been removed (Bertuch 2016).

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)

Overview

Of the 73 original skeletal samples, 67 underwent LA-ICP-MS analysis (Figure 4.6). One of the primary reasons that LA-ICP-MS was used for this project was that it required very little bone (micrograms instead of milligrams), requires minimal preparation and is comparatively fast compared to other similar techniques.



Figure 4.6 Photograph of the LA-ICP-MS set up at Southern Cross University, NSW. Author's photo.

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Preparation of Skeletal Samples for LA-ICP-MS

Preparation of bone pieces for LA-ICP-MS was conducted at Southern Cross University, Geosciences Department in NSW, under the supervision of Dr Renaud Johannes-Boyau and Dr Ian Moffat. Bone pieces ranging between 0.3 to 1 mg were cleaned and abraded to remove external contaminants. Bone pieces were then cut with a small bone saw, to expose the inner surface for laser ablation.

Laser Ablation (LA)

Skeletal samples were pressed with a glass plate into aluminium cups lined with adhesive putty to ensure the surface was flush with the top of the sample holder. This corresponded to the focal plane of the laser in the sampling cell. Elemental cross sections were measured using an 80 μ m laser spot size, with the pulse frequency set to 10 Hz. Multiple spots on the bone were undertaken during the analysis to ascertain the accuracy of the data acquisition and to increase the spatial accuracy of the results (Figure 4.7).



Figure 4.7 Samples undergoing laser ablation. Author's photo.

Laser ablation samples were run on a LA-esi-NWR (New Wave Revolution 213) laser ablation system coupled to an Agilent 7700 ICPMS. Elemental concentrations and ratios were determined after background subtraction using the NIST glass standards 610 and 612. A cleaning run was also conducted prior to analysis to remove contamination from the topmost microns of the sample.

Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

As mentioned previously, mass spectrometry is used to determine the masses and abundances of naturally occurring isotopes. Mass spectrometers are designed to 'separate charged atoms and molecules on the basis of their masses, based on their motions in magnetic fields' (Faure and Mensing 2009:64). In ICP-MS analyses, samples are carried into the plasma by argon gas and broken down into elements and ionised. The ions then enter a magnetic selector device, which separates them based on their mass to charge ratio before they are collected in a charge sensitive detector (Pollard et al. 2007:61). Using this method, most elements can be analysed, as ICP-MS provides detection limits in the order of parts per thousand, with only elements with a low atomic mass being an exception (Pollard et al. 2007:61).

Elemental concentrations for this research were measured with an Agilent 7700 (x lenses) by monitoring for the isotopes: ⁴³Ca, ⁴⁴Ca, ⁸⁸Sr, ¹³⁷Ba and ²³⁸U. These elements were selected for the information they can provide about mobility and post-mortem diagenesis (see Reynard and Balter 2014).

Data Reduction

Data collected using the ICP-MS were analysed using Iolite 3.32 (Paton et al. 2011) using the trace element data reduction scheme (Woodhead et al. 2007).

Justification of Methods

Laser ablation inductively coupled plasma mass spectrometry was used for this part of the research as it is a minimally destructive process, which can simultaneously measure a number of elements. As mentioned previously, only a small amount of bone could be sampled from the collection for analysis for this research. This bone had to be split between three isotopic methods and **Bianca Waldie** 201 radiocarbon dating, therefore LA-ICP-MS was a perfect solution for the limited materials available and allowed further analysis of diet, mobility and diagenetic contamination within the population sample. Furthermore, Iolite was the chosen data reduction program used in this research due to its flexibility and visual environment. Every step of the data process can be visually inspected using Iolite, which made it easier to identify problem areas within the sample set and correct them immediately.

Statistical Analysis

Overview

Statistical analysis was used in this research to compare the overall values of two sample sets and assess whether the difference between the values was significant or not. Temporal periods, males vs. females and adults vs. sub-adults were all analysed against each other using unpaired t-tests (otherwise known as student t-tests).

A t-test is an investigation of two populations' means through the use of statistical analysis (Drennan 2009:153). Unpaired t-tests are used to measure the difference in the means of two different sample sets that do not have a natural pairing (such as the samples within the populations at the Fénix Archaeological Complex), instead of paired t-tests, which compare the same study subjects at two different times (Drennan 2009:153).

Calculations for the t-tests were calculated as per the methods of Drennan (2009:153–154). All statistics were correlated at a standard 95% probability (Drennan 2009:155). In the results chapter the significance test results will be set out according to the flowing example:

(t=2.5, 0.3 > p > 0.0198)

Where 't' represents the type of significance test used, the first number (2.5) represents the pooled standard errors and the second number (0.3) represents the standard error of difference. The letter 'p' stands for the probability and the number after is the two tailed probability value, which represents the significance of the test (Drennan 2009:155).

The t-test gives the probability that the distance between the two means is caused by chance. If the probability is less than 0.05, then the difference is significant and not caused by chance.

Justification of Methods

T-tests were used in this research as they are ideal for this kind of analysis because they allow the information from both samples to be pooled into a single statement of probability (Drennan 2009:153). The unpaired t-tests in this study indicate whether or not the difference between the two groups' averages (e.g., males and females), most likely reflects a "real" difference in the population or is just due to the vagaries of sampling (Drennan 2009:155).

Chapter Summary

This chapter summarised the procedures used for sample collection, processing and analysis of stable carbon, nitrogen and oxygen isotope analysis, radiocarbon dating and LA-ICP-MS of human skeletal material.

Overview

This chapter summarises the results from all isotopic and elemental analyses conducted as part of this research. An overview of the stable carbon, nitrogen and oxygen isotopic results, along with skeletal ID, sex and relative and/or chronometric dates is listed below (Table 5.1) (see Appendix D for raw data). Additionally, an overview of strontium, barium, calcium and uranium values are reported later in the chapter. Relative dates are estimated based on cultural chronologies and cross-referenced with relative stratigraphy in relation to radiocarbon determinations.

Table 5.1 Stable isotopic results for individuals from the Fénix Archaeological Collection. F= female. M= male. I= indeterminate. A= adult. SA= sub-adult. *= radiocarbon date. $\delta^{13}C_{col}$ = bone collagen value. $\delta^{13}C_{ap}$ = bone apatite value. $\delta^{13}C_{col-ap}$ = collagen to apatite spacing.

ID	Sex	Age	Chronology	δ ¹³ Ccol	$\delta^{15}N$	δ ¹³ Cap	δ ¹³ Ccol-ap	δ ¹⁸ 0
F2-E1	F	А	1698-1522 cal BP*	-18.8	10.1	-	-	-
F2-E2	Ι	SA	c. 2200-1000 BP	-17.4	8.9	-8.4	9.0	-5.7
F3-E1	F	А	c. 6000-2200 BP	-19.3	10.8	-8.4	10.9	-6.5
F3-E2	М	А	2684-2349 cal BP*	-17.3	12.6	-	-	-
F3-E3	М	А	c. 2200-1000 BP	-16.1	13.7	-7.6	8.6	-6.4
F3-E4	F	А	c. 6000-2200 BP	-17.6	12.3	-8.5	9.1	-4.6
F3-E5	F	А	c. 2200–1000 BP	-15.3	11.5	-6.7	8.6	-6.6
F3-E6	F	А	c. 2200-1000 BP	-18.7	10.8	-8.2	10.5	-6.9
F3-E7	Ι	Ι	c. 2200-1000 BP	-20.4	7.0	-9.5	10.9	-5.5
F3-E9	Ι	SA	c. 6000-2200 BP	-15.9	14.3	-7.5	8.4	-8.1
F3-E10	М	А	c. 2200-1000 BP	-15.9	14.2	-7.8	8.1	-7.9
F3-E12	F	А	c. 6000-2200 BP	-15.8	10.9	-7.6	8.2	-6.7
F3-E13	М	Ι	c. 6000-2200 BP	-17.5	11.9	-8.0	9.5	-6.3
F3-E14	М	А	c. 6000-2200 BP	-20.1	7.7	-9.5	10.6	-6.7
F3-E15	М	А	c. 2200-1000 BP	-16.7	12.4	-7.5	9.2	-6.6
F3-E16	Ι	SA	c. 6000-2200 BP	-17.3	12.9	-	-	-
F3-E17	Ι	SA	775–557 cal BP*	-13.9	8.0	-	-	-
F3-E18	Ι	SA	c. 2200-1000 BP	-13.5	13.9	-5.3	8.2	-7.1
F3-E19	Ι	SA	c. 6000-2200 BP	-	-	-7.0	-	-8.3
F3-E20	Ι	SA	c. 2200-1000 BP	-16.8	9.9	-6.9	10.0	-8.7
F3-E21	F	А	c. 6000-2200 BP	-17.2	12.4	-8.0	9.2	-5.1
F3-E22	М	А	c. 2200-1000 BP	-15.4	13.3	-7.9	7.5	-6.7
F3-E23	М	А	c. 2200-1000 BP	-17.7	12.9	-7.7	10.0	-5.5
F3-E24	Μ	Α	c. 6000-2200 BP	-15.4	13.3	-6.5	8.9	-4.3
F3-E25	Ι	А	c. 2200-1000 BP	-16.2	13.6	-7.6	8.7	-6.9
F3-E26	Ι	A	c. 2200-1000 BP	-18.0	7.7	-7.3	10.7	-6.7

F3-E27	F	А	c. 2200–1000 BP	-18.7	11.1	-8.1	10.6	-5.4
F3-E28	М	SA	c. 2200–1000 BP	-18.7	11.4	-7.5	11.2	-8.0
F3-E29	F	А	c. 2200-1000 BP	-17.8	12.0	-7.3	10.5	-7.2
F3-E30	М	А	c. 2200-1000 BP	-	-	-9.6	-	-6.2
F3-E31	F	Α	2052-1883 cal BP*	-17.9	11.5	-	-	-
F3-E32	Ι	А	c. 2200-1000 BP	-17.2	12.7	-8.6	8.6	-5.9
F3-E33	М	Α	c. 2200-1000 BP	-17.5	12.8	-8.6	9.0	-6.3
F3-E34	F	А	c. 2200–1000 BP	-16.8	12.9	-8.1	8.7	-6.7
F3-E35	Ι	А	c. 2200-1000 BP	-14.0	14.0	-6.5	7.5	-6.1
F3-E36	Ι	SA	c. 6000-2200 BP	-	-	-7.0	-	-4.9
F3-E37	F	А	c. 2200–1000 BP	-16.6	13.4	-8.0	8.6	-7.4
F3-E38	М	Α	c. 2200–1000 BP	-13.5	12.5	-6.1	7.4	-7.3
F3-E39	F	А	c. 2200–1000 BP	-19.4	10.4	-9.8	9.6	-7.0
F3-E40	М	Α	c. 2200–1000 BP	-16.3	13.6	-8.0	8.3	-6.6
F3-E41	М	SA	c. 6000-2200 BP	-14.6	15.2	-8.3	6.4	-4.2
F3-E42	М	А	c. 2200–1000 BP	-16.5	13.9	-8.5	8.0	-5.0
F3-E43	М	Α	c. 2200–1000 BP	-18.9	8.8	-8.4	10.5	-5.3
F3-E44	F	Α	c. 2200–1000 BP	-18.3	11.4	-8.9	9.4	-5.9
F3-E45	М	SA	c. 2200–1000 BP	-17.3	13.0	-8.1	9.2	-6.6
F3-E46	Ι	Α	c. 2200–1000 BP	-17.0	12.8	-8.7	8.3	-7.4
F3-E47	F	Α	c. 2200–1000 BP	-15.2	13.8	-6.7	8.5	-5.6
F3-E48	Ι	Α	c. 2200–1000 BP	-20.5	8.3	-9.4	11.1	-7.3
F3-E49	F	Α	c. 6000-2200 BP	-15.4	14.4	-7.7	7.7	-5.7
F3-E50	Ι	SA	c. 2200–1000 BP	-18.8	11.1	-8.0	10.8	-7.2
F3-E51	F	Α	c. 6000-2200 BP	-17.6	12.1	-8.0	9.6	-4.7
F3-E53	Ι	Ι	c. 2200–1000 BP	-17.3	13.2	-8.2	9.1	-6.3
F3-E55	М	Α	c. 2200–1000 BP	-15.0	14.5	-	-	-
F3-E56	Ι	SA	c. 2200–1000 BP	-14.3	9.1	-6.7	7.6	-5.1
F3-E57	Ι	SA	c. 6000-2200 BP	-13.9	10.0	-6.4	7.6	-5.8
F3-E58	Ι	Α	c. 2200–1000 BP	-13.0	17.2	-4.9	8.1	-5.7
F3-E59	Ι	SA	c. 6000–2200 BP	-13.8	16.6	-5.6	8.2	-6.8
F3-E60	М	А	c. 6000–2200 BP	-17.2	13.3	-6.2	11.0	-7.8
F3-E61	F	А	c. 6000–2200 BP	-17.7	12.5	-5.9	11.8	-8.9
F3-E63	Ι	SA	c. 6000–2200 BP	-	-	-6.2	-	-4.5
F3-E64	I	SA	c. 6000–2200 BP	-14.2	16.1	-4.7	9.6	-8.0
F3-E65	М	A	c. 1000–550 BP	-17.3	14.5	-6.8	10.5	-7.5
F3-E66	F	A	c. 2200–1000 BP	-20.5	7.1	-5.7	14.8	-8.2
F3-E67	I	Α	c. 2200–1000 BP	-16.5	10.0	-6.5	10.0	-7.1
F3-E68	М	Α	5315-4921 cal BP*	-13.7	15.6	-	-	-
F3-E69	М	А	c. 6000–2200 BP	-15.2	14.7	-8.8	6.4	-8.1
F8-E1	F	Α	c. 2200–1000 BP	-16.5	9.3	-6.7	9.8	-6.9
F8-E2	I	SA	c. 2200–1000 BP	-19.8	9.5	-8.3	11.5	-7.0
F8-E3	М	A	1575–1404 cal BP*	-19.0	9.0	-	-	-
F8-E4	М	A	c. 2200–1000 BP	-17.8	10.6	-7.9	9.9	-7.5
F8-E5	I	SA	c. 2200–1000 BP	-18.4	9.6	-8.5	9.9	-7.4
F8-E6	F	A	c. 2200–1000 BP	-19.5	8.9	-8.0	11.5	-5.9
F12-E1	F	A	c. 2200–1000 BP	-17.8	11.4	-9.1	8.7	-7.2

A total of 73 human skeletal samples were analysed for stable carbon, nitrogen and oxygen isotopes, multi-elemental composition and radiocarbon ages. Full elemental analyses and radiocarbon results are listed later in this chapter.

Stable Carbon and Nitrogen Isotope Results

Overview

Mean stable carbon and nitrogen isotope values for all of the individuals analysed from the Fénix Archaeological Complex are -16.9 ± 1.9‰ for $\delta^{13}C_{col}$ and -11.9 ± 2.3‰ for $\delta^{15}N$, with values ranging from -20.5‰ to -13.0‰ for $\delta^{13}C_{col}$ and 7.0‰ to 17.2‰ for $\delta^{15}N$.

Fénix Archaeological Complex: Inter-Site Results

Results for the stable carbon and nitrogen isotope analysis of the Fénix Osteological Collection are compared with similar studies conducted in central Chile (Table 5.2).

Table 5.2 Summaries (mean ± standard deviation) of human bone collagen stable carbon and nitrogen isotope results for a selection of geographically representative (coastal, mountain, valley) archaeological sites in Chile in comparison to the Fénix Archaeological Complex. Data table adapted from Aufderheide and Santoro (1999), Falabella et al. (2007), Roberts et al. (2013), Sanhueza and Falabella (2010) and Tykot et al. (2009).

Population	N	δ ¹³ Ccol (‰) X ± SD	Range	δ ¹⁵ N (‰) X ± SD	Range
Molle Pampa Medio	10	-12.8 ± 3.7	-17.6, -9.6	19.6 ± 3.2	10.5, 17.3
Valle Verde	6	-20.1 ± 0.3	-20.3, -19.6	4.5 ± 0.7	3.8, 5.5
Maria Pinto	6	-12.0 ± 0.8	-12.7, -10.7	7.2 ± 0.7	6.7, 8.1
LEP-C	9	-16.4 ± 2.3	-19.8, -13.5	10.5 ± 1.9	7.0, 13.1
Las Brisas 10–14	6	-13.9 ± 1.8	-17.3, -12.3	10.1 ± 2.4	8.1, 14.3
Cancha de Golf 1	4	-17.6 ± 1.0	-19.0, -16.6	10.2 ± 1.2	9.0, 11.3
Chacayes	2	-15.0 ± 5.2	-18.6, -11.3	6.6 ± 1.4	5.6, 7.6
Fénix	69	-16.9 ± 1.9	-20.5, -13.0	11.9 ± 2.3	7.0, 17.2

To date, the Fénix Archaeological Complex has provided the largest single site skeletal population sample set (n=69) analysed for stable carbon and nitrogen isotopes in Chile. Stable carbon and nitrogen isotope values from the population

at the Fénix Archaeological Complex are most comparable to the sites of LEP-C and Cancha de Golf 1 (Figure 5.1).



Figure 5.1 Mean results for stable carbon and nitrogen isotope values for Fénix in comparison to other central Chilean sites, and baseline values for C_3 (European farmers), C_4 (maize farmers) and marine diets (see Little and Schoeninger 1995; Schoeninger et al. 1983). \blacksquare = Global representative samples.

The Fénix Archaeological Complex population is least comparable to the sites of Molle Pampa Medio, Valle Verde and Maria Pinto, which serve as endpoints for the consumption of marine mammals, $100\% C_3$ terrestrial and C₄ maize farmers.

Fénix Archaeological Complex: Intra-Site Results

Stable carbon and nitrogen isotopic composition of human dietary protein from the Fénix Osteological Collection indicates a range of values throughout the population with the largest range being within the area of Fénix 3 (Figure 5.2). Stable carbon and nitrogen bone collagen isotopic values for Fénix 3 cluster mainly between -20.5‰ and -13.0‰ for $\delta^{13}C_{col}$ and 7.0‰ and 17.2‰ for $\delta^{15}N$.



Figure 5.2 Intra-site comparison between Fénix 2, Fénix 3, Fénix 8 and Fénix 12 individuals against mean stable isotope signals for C_3 , C_4 and marine values (see Roberts et al. 2013; Schoeninger and DeNiro 1983; Tykot et al. 2009). \blacksquare = Representative samples from central Chile.

- ♦= Fénix 2 (2 individuals)
- Fénix 3 (60 individuals)
- ▲= Fénix 8 (6 individuals)
- ●= Fénix 12 (1 individual)

The sites of Fénix 2, Fénix 8 and Fénix 12 demonstrate values that cluster between -19.8‰ and -16.5‰ for $\delta^{13}C_{col}$ and 8.9‰ and 11.4‰ for $\delta^{15}N$, with a range of -20.5‰ to -13.0‰ for $\delta^{13}C_{col}$ and 7.0‰ to 17.2‰ for $\delta^{15}N$.

Overall Results: Male vs. Female

Average stable carbon and nitrogen isotopic values for females within the population were -17.6 ± 1.4‰ for $\delta^{13}C_{col}$ and 11.5 ± 1.7‰ for $\delta^{15}N$, with a range of -20.5‰ to -15.2‰ for $\delta^{13}C_{col}$ and 7.1‰ to 14.4 for $\delta^{15}N$. Comparably, the mean values for males within the population were -16.7 ± 1.7‰ for $\delta^{13}C_{col}$ and

12.7 ± 2.0‰ for δ^{15} N, with a range of -20.1‰ to -13.5‰ for δ^{13} C_{col} and 7.7‰ to 15.6‰ for δ^{15} N (Figure 5.3).



Figure 5.3 Mean stable carbon and nitrogen isotopic values for males and females at the Fénix Archaeological Complex.

- •= Male (24 Individuals)
- ▲= Female (22 Individuals)

The 0.5‰ difference in $\delta^{13}C_{col}$ values between males and females in the sample population is not statistically significant (t= 2.0, 0.5 > p > 0.0577). However, the 1.2‰ difference in $\delta^{15}N$ values, between males and females in the sample population, is statistically significant (t= 2.3, 0.5 > p > 0.0258).

Overall Results: Adults vs. Subadults

Mean stable carbon and nitrogen isotopic values for adults within the population sample set were -17.0 ± 1.6‰ for $\delta^{13}C_{col}$ and 12.1 ± 2.2‰ for $\delta^{15}N$, with a range of -20.5‰ to -13.0‰ for $\delta^{13}C_{col}$ and 7.1‰ to 15.6‰ for $\delta^{15}N$. Mean values for sub-adults were -16.3 ± 2.2‰ for $\delta^{13}C_{col}$ and 11.6 ± 2.7‰ for $\delta^{15}N$, with a range of -19.8‰ to -13.5‰ for $\delta^{13}C_{col}$ and 8.0‰ to 16.6‰ for $\delta^{15}N$ (Figure 5.4).



Figure 5.4 Mean stable carbon and nitrogen isotopic values for adults and sub-adults at the Fénix Archaeological Complex.

- •= Adult (52 individuals)
- ▲= Sub-adult (15 individuals)

The 0.8‰ difference in $\delta^{13}C_{col}$ values between adults and sub-adults in the sample population is not statistically significant (t= 1.4, 0.5 > p > 0.1716). The 0.5‰ difference in $\delta^{15}N$ values, between adults and sub-adults in the sample population, is also not statistically significant (t= 0.7, 0.7 > p > 0.4787).

Temporal Results

The mid-late Archaic Period (c. 7000–2200 BP) at the Fénix Archaeological Complex displays mean isotopic values of -16.3 ± 1.8‰ for $\delta^{13}C_{col}$ and 13.0 ± 2.1‰ for $\delta^{15}N$, with a range of -20.1‰ to -13.7‰ for $\delta^{13}C_{col}$ and 7.7‰ to 16.6‰ for $\delta^{15}N$ (Figure 5.5). Additionally, stable carbon and nitrogen isotopic results for the Early Ceramic Period (c. 2200–1000 BP) suggest more negative $\delta^{13}C_{col}$ values and less positive $\delta^{15}N$ values, with mean values being -17.2 ± 1.9‰ for $\delta^{13}C_{col}$ and 11.5 ± 2.2‰ for $\delta^{15}N$, with a range of -20.5‰ to -13.0‰ for $\delta^{13}C_{col}$ and 7.0‰ to 17.2‰ for $\delta^{15}N$.

The 0.9‰ difference in $\delta^{13}C_{col}$ values between the mid-late Archaic Period and the Early Ceramic Period in the sample population is not statistically significant (t= 1.8, 0.5 > p > 0.0717). Conversely, the 1.5‰ difference between $\delta^{15}N$ values amid the sample population from the mid-late Archaic and the Early Ceramic Period is considered to be statistically significant (t= 2.7, 0.6 > p > 0.0099).



Figure 5.5 Mean stable carbon and nitrogen isotope results for the Fénix Archaeological Complex different chronological periods.

- = Mid-late Archaic Period = c. 6000–2200 BP (21 individuals)
- ◆= Early Ceramic Period = c. 2200–1000 BP (46 individuals)
- ▲= Late Intermediate Period = c. 1000–550 BP (2 individuals)

Mean values for the Late Intermediate Period (c. 1000–550 BP) illustrate similar stable nitrogen isotopic values to the Early Ceramic Period with a less negative mean stable carbon isotopic value of -15.6 ± 2.4‰ and a comparably similar δ^{15} N value of 11.3 ± 4.6‰. However, it is pertinent to note that there are only two individuals dated to the Late Intermediate Period (F3-E17 and F3-E65).

The 1.6‰ difference in $\delta^{13}C_{col}$ values between the Early Ceramic Period and the Late Intermediate Period is not statistically significant (t= 1.9, 0.9 > p > 0.0707). The 0.16‰ difference in $\delta^{15}N$ values for the sample population between the Early Ceramic Period and the Late Intermediate Period is also not statistically significant (t= 0.1, 1.7 > P > 0.9240).

Mid-Late Archaic Period (c. 6000–2200 BP): Males vs. Females

Mean stable carbon and nitrogen isotopic values for females within the mid-late Archaic Period population were -17.1 ± 1.2‰ for $\delta^{13}C_{col}$ and 12.3 ± 1.2‰ for $\delta^{15}N$, with a range of -19.3‰ to -15.4‰ for $\delta^{13}C_{col}$ and 10.8‰ to 13.4 for $\delta^{15}N$. Comparably, the mean values for males within the population were -16.4 ± 2.0‰ for $\delta^{13}C_{col}$ and 13.0 ± 2.5‰ for $\delta^{15}N$, with a range of -20.1‰ to -13.7‰ for $\delta^{13}C_{col}$ and 7.7‰ to 15.6‰ for $\delta^{15}N$ (Figure 5.6).



Figure 5.6 Mean stable carbon and nitrogen isotope results for females and males during the mid-late Archaic Period for the Fénix Archaeological Complex.

- = Males (8 individuals)
- ▲= Females (8 individuals)

Furthermore, the 0.7‰ difference in $\delta^{13}C_{col}$ values between males and females in the sample population is not considered to be statistically significant (t= 0.8, 0.8 > p > 0.4211). The 0.7‰ difference in $\delta^{15}N$ values between males and females is also considered to not be statistically significant (t= 0.7, 1.0 > p > 0.4887).

Mid-Late Archaic Period (c. 6000-2200 BP): Adults vs. Sub-Adults

Mean stable carbon and nitrogen isotopic values for adults within the mid-late Archaic Period population sample set were -16.8 ± 1.7‰ for $\delta^{13}C_{col}$ and 12.6 ± 1.9‰ for $\delta^{15}N$, with a range of -20.1‰ to -13.7‰ for $\delta^{13}C_{col}$ and 7.7‰ to 15.6‰ for $\delta^{15}N$. Mean values for sub-adults were -15.0 ± 1.4‰ for $\delta^{13}C_{col}$ and -14.2 ± 2.4‰ for $\delta^{15}N$, with a range of -17.3‰ to -13.8‰ for $\delta^{13}C_{col}$ and 10.0‰ to 16.6 for $\delta^{15}N$ (Figure 5.7).



Figure 5.7 Mean stable carbon and nitrogen isotope results for adults and sub-adults during the mid-late Archaic Period for the Fénix Archaeological Complex.

- = Adult (14 individuals)
- ▲= Sub-adult (6 individuals)

The 1.9‰ difference for $\delta^{13}C_{col}$ values between adults and sub-adults in the sample population for the mid-late Archaic Period is considered to be statistically significant (t= 2.4, 0.8 > p > 0.0262). Conversely, the 1.6‰ difference for $\delta^{15}N$ values between adults and sub-adults is not considered to be statistically significant (t= 1.6, 1.0 > p > 0.1341).

Early Ceramic Period Samples (c. 2200-1000 BP): Males vs. Females

Mean stable carbon and nitrogen isotopic values for females within the Early Ceramic Period population were -17.9 ± 1.5‰ for $\delta^{13}C_{col}$ and 10.9 ± 1.7‰ for $\delta^{15}N$, with a range of -20.5‰ to -15.2‰ for $\delta^{13}C_{col}$ and 7.1‰ to 13.8‰ for $\delta^{15}N$. Comparably, the mean values for males within the population were -16.7 ± 1.5‰ for $\delta^{13}C_{col}$ and 12.7 ± 1.5‰ for $\delta^{15}N$, with a range of -19.0‰ to -13.5‰ for $\delta^{13}C_{col}$ and 9.0‰ to 14.5‰ for $\delta^{15}N$ (Figure 5.8).



Figure 5.8 Mean stable carbon and nitrogen isotope results for males and females during the Late Intermediate Period for the Fénix Archaeological Complex.

- = Males (14 individuals)
- ▲= Females (14 individuals)

The 1.2‰ difference in $\delta^{13}C_{col}$ values between males and females in the Early Ceramic Period sample population is statistically significant (t= 2.1, 0.6 > p > 0.0458). Additionally, the 1.8‰ difference in $\delta^{15}N$ values, between males and females in the sample population is also statistically significant (t= 3.0, 0.6 > p > 0.0061).

Early Ceramic Period Samples (c. 2200–1000 BP): Adults vs. Sub-Adults

Average stable carbon and nitrogen isotopic values for adults within the Early Ceramic Period population sample set were -17.2 \pm 1.8‰ for $\delta^{13}C_{col}$ and 11.7 \pm 2.3‰ for $\delta^{15}N$, with a range of -20.5‰ to -13.0‰ for $\delta^{13}C_{col}$ and 7.1‰ to 14.5‰ for $\delta^{15}N$. Mean values for sub-adults were -17.0 \pm 2.1‰ for $\delta^{13}C_{col}$ and -10.8 \pm 1.7‰ for $\delta^{15}N$, with a range of -18.8‰ to -13.5‰ for $\delta^{13}C_{col}$ and 8.9‰ to 13.9 for $\delta^{15}N$ (Figure 5.9).



Figure 5.9 Mean stable carbon and nitrogen isotope results for adults and sub-adults during the Early Ceramic Period for the Fénix Archaeological Complex.

- = Adult (34 individuals)
- ▲= Sub-adult (10 individuals)

Furthermore, the 0.2‰ difference in $\delta^{13}C_{col}$ values between adults and subadults in the Early Ceramic Period sample population is not statistically significant (t= 0.3, 0.6 > p > 0.7684). The 0.9‰ difference in $\delta^{15}N$ values, between adults and sub-adults in the sample population, is not statistically significant (t= 1.2, 0.8 > p > 0.2509).

Late Intermediate Period (c. 1000-550 BP): Males vs. Females

The Late Intermediate Period only has two individuals and one of those is of an indeterminate sex therefore differences between the sexes cannot be determined.

Late Intermediate Period (c. 1000-550 BP): Adult vs. Sub-Adult

Stable carbon and nitrogen isotopic values for the Late intermediate Period adult were -17.3‰ for $\delta^{13}C_{col}$ and 14.5‰ for $\delta^{15}N$. The stable carbon and nitrogen isotope values for the Late Intermediate Period sub-adult were -13.9‰ for $\delta^{13}C_{col}$ and -8.0‰ for $\delta^{15}N$ (Figure 5.10).



Figure 5.10 Mean stable carbon and nitrogen isotope results for adults and sub-adults during the Late Intermediate Period for the Fénix Archaeological Complex.

- •= Adult (1 individual)
- ▲= Sub-adult (1 individual)

However, due to the sample size in this population (two individuals), information about the Late Intermediate Period population as a whole cannot be statistically examined.

Oxygen Isotope Results

Fénix Osteological Collection: Inter-Site Results

Results for the stable oxygen and carbon bone carbonate isotope analysis of individuals from the Fénix Archaeological Collection are compared with similar studies conducted in central Chile (Table 5.3). As mentioned previously, the Fénix Archaeological Complex has the largest single site population sample set isotopically analysed from Chile.

Table 5.3 Summaries (mean ± standard deviation) of human bone apatite stable carbon and oxygen isotope results for a selection of geographically representative (coast, mountain, valley) archaeological sites in Chile in comparison to individuals from the Fénix Archaeological Complex. Data table adapted from Aufderheide and Santoro (1999), Falabella et al. (2007), Roberts et al. (2013), Sanhueza and Falabella (2010) and Tykot et al. (2009).

Population	N	δ ¹³ Cap (‰) X ± SD	Range	δ ¹⁸ 0 (‰) X ± SD	Range
El Mercurio	10	-9.3 ± 1.7	-10.6, -4.7	-8.7 ± 1.5	-10.1, -8.0
Valle Verde	5	-12.3 ± 1.3	-13.5, -10.0	-8.8 ± 0.4	-9.3, -8.2
LEP-C	8	-10.2 ± 1.3	-11.8, -8.2	-3.2 ± 0.6	-4.5, -3.1
Las Brisas 10–14	6	-7.9 ± 2.5	-12.7, -6.2	-4.3 ± 0.5	-5.1, -3.7
Cancha de Golf 1	4	-10.0 ± 1.6	-12.1, -8.3	-3.6 ± 0.6	-4.5, -3.1
Chacayes	2	-8.5 ± 2.5	-10.3, -6.7	-8.4 ± 1.2	-9.2, -7.5
Fénix	66	-7.8 ± 1.1	-8.7, -4.2	-6.4 ± 1.0	-9.8, -4.5

Mean stable carbon and oxygen isotopic composition of average human dietary protein for bone apatite from the Fénix Archaeological Complex was plotted against other central Chilean archaeological sites for comparison of geographical variability throughout central Chile (Figure 5.11).



Figure 5.11 Mean stable carbon and oxygen isotope results for the Fénix Archaeological Complex in comparison to other central Chilean sites.

- = Coastal sites
- ▲= Valley sites
- ♦= Highland sites

Mean values for individuals from the Fénix Archaeological Complex are -6.4 ± 1.0% (δ^{18} O) and -7.8 ± 1.1% ($\delta^{13}C_{ap}$), with values ranging from -9.8‰ to - 4.5% for δ^{18} O and -8.7‰ to -4.2% for $\delta^{13}C_{ap}$.

Fénix Osteological Collection: Intra-Site Results

Stable carbon and oxygen isotopic composition of human bone apatite at the Fénix Archaeological Complex indicates a range of values throughout the population with the largest range being within the site of Fénix 3, due to the larger sample population (Figure 5.12).



Figure 5.12 Intra-site stable carbon and oxygen isotope value comparison between individuals from Fénix 2, Fénix 3, Fénix 8 and Fénix 12.

- ♦= Fénix 2 (1 individual)
- Fénix 3 (59 individuals)
- ▲= Fénix 8 (5 individuals)
- •= Fénix 12 (1 individual)

Stable carbon and oxygen bone apatite values for Fénix 3 cluster primarily between -9.0‰ and -7.0‰ for $\delta^{13}C_{ap}$ and -8.0‰ and -5.0‰ for $\delta^{18}O$, respectively, indicating movement between the coast and interior valley areas. Outliers from this cluster demonstrate higher $\delta^{13}C_{ap}$ values, with some slightly more negative and less negative $\delta^{18}O$ values, demonstrating a lack of homogeneity within the population. Similarly, the sites of Fénix 2, Fénix 8 and Fénix 12 demonstrate values that cluster between -6.0‰ and -10.0‰ for $\delta^{13}C_{ap}$ and -5.0‰ and -8.0‰ for $\delta^{18}O$.

Males vs. Females

Mean $\delta^{13}C_{ap}$ and $\delta^{18}O$ isotopic values for females within the population were -6.2 $\pm 0.8\%$ for $\delta^{18}O$ and -8.1 $\pm 0.8\%$ for $\delta^{13}C_{ap}$, with a $\delta^{18}O$ range of -7.4‰ to -4.6‰ and a $\delta^{13}C_{ap}$ range of -9.8‰ to -6.7‰ (Figure 5.13). Comparably, the mean values for males within the population were -6.4 $\pm 1.1\%$ for $\delta^{18}O$ and -8.0 $\pm 0.8\%$ for $\delta^{13}C_{ap}$, with a $\delta^{18}O$ range of -8.1‰ to -4.2‰ and a $\delta^{13}C_{ap}$ range of -9.8‰ to -6.7‰ to -4.2‰ and a $\delta^{13}C_{ap}$ range of -9.8‰ to -6.7‰, indicating a reasonable amount of heterogeneity between $\delta^{18}O$ and $\delta^{13}C_{ap}$ values within both male and female groups within the Fénix population.



Figure 5.13 Mean stable carbon and oxygen isotopic results comparing males and females for the Fénix Archaeological Complex.

- = Males (22 individuals)
- ▲= Females (21 individuals)

The 0.1‰ difference in $\delta^{13}C_{ap}$ values between males and females in the sample population is not statistically significant (t= 0.4, 0.3 > p > 0.7113). Additionally, the 0.2‰ difference in δ^{18} O values, between males and females in the sample population, is also not statistically significant (t= 0.6, 0.3 > p > 0.5391).

Adults vs. Sub-Adults

Mean isotopic values for adults within the Fénix population were -8.0 ± 0.9 for δ^{18} O and -6.3 ± 0.9‰ for $\delta^{13}C_{ap}$, with a δ^{18} O range of -8.1‰ to -4.2‰ and a $\delta^{13}C_{ap}$ range of -9.6‰ to -5.7‰. Mean values for sub-adults were -6.8 ± 1.9‰ for δ^{18} O and -7.0 ± 1.3‰ for $\delta^{13}C_{ap}$, with a δ^{18} O range of -8.7‰ to -4.7‰ and a $\delta^{13}C_{ap}$ range of -8.9‰ to -4.5‰, illustrating similar heterogeneity, as was found within the adult population sample (Figure 5.14).



Figure 5.14 Mean results comparing adult to sub-adult stable carbon an oxygen isotope values at the Fénix Archaeological Complex.

- = Adult (48 individuals)
- ▲= Sub-adult (16 individuals)

The 0.9‰ difference in $\delta^{13}C_{ap}$ values between adults and sub-adults in the sample population is considered to be statistically significant (t= 3.2, 0.3 > p > 0.0021). However, the 0.5‰ difference in δ^{18} O values, between adults and sub-adults in the sample population, is not statistically significant (t= 1.7, 0.3 > p > 0.0852).
Temporal Results

The mid-late Archaic Period (c. 6000–2200 BP) at the Fénix Archaeological Complex shows mean isotopic values of -6.0 ± 1.3‰ for δ^{18} O and -7.6 ± 1.1‰ for δ^{13} C_{ap} (Figure 5.15).



Figure 5.15 Mean stable carbon and oxygen isotope results for the Fénix Archaeological Complex for the different chronological periods.

- = Mid-late Archaic Period = c. 6000–2200 BP (21 individuals)
- ◆= Early Ceramic Period = c. 2200–1000 BP (44 individuals)
- ▲= Late Intermediate Period = c. 1000–550 BP (1 individual)

Additionally, results indicate more negative δ^{18} O and $\delta^{13}C_{ap}$ values in the Early Ceramic Period (c. 2200–1000 BP), with mean values being -6.5 ± 0.8‰ for δ^{18} O and -7.8 ± 1.1‰ for $\delta^{13}C_{ap}$. Mean values for the Late Intermediate Period (c. 1000–550 BP) were -6.8‰ for δ^{18} O and -7.5‰ for $\delta^{13}C_{ap}$. However, it is relevant to note that there is only one individual dated to the Late Intermediate Period for stable oxygen isotope analysis (F3-E65), with values of -6.8‰ for δ^{18} O and -7.5‰ for $\delta^{13}C_{ap}$.

Statistical analysis of the values between samples sets indicate that the 0.2%difference in $\delta^{13}C_{ap}$ values between the mid-late Archaic Period sample set and the Early Ceramic Period sample set are not statistically significant (t= 0.6, 0.3 > p > 0.5321). However, the 0.5‰ difference in δ^{18} O values between the mid-late Archaic Period sample set and the Early Ceramic Period sample set are considered to be statistically significant (t= 2.0, 0.3 > p > 0.0499). Statistics were not conducted for the Late Intermediate Period due to there only being one sample for that time period.

Mid-Late Archaic Period (c. 6000-2200 BP): Males vs. Females

Mean $\delta^{13}C_{ap}$ and $\delta^{18}O$ isotopic values for females within the mid-late Archaic Period population were -5.8 ± 1.0‰ for $\delta^{18}O$ and -8.1 ± 0.4‰ for $\delta^{13}C_{ap}$, with a $\delta^{18}O$ range of -7.4‰ to -4.6‰ for $\delta^{18}O$ and -8.9‰ to -7.8‰ for $\delta^{13}C_{ap}$ (Figure 5.16). Comparably, the mean values for males within the population were -6.0 ± 1.5‰ for $\delta^{18}O$ and -8.1 ± 1.0‰ for $\delta^{13}C_{ap}$, with a $\delta^{18}O$ range of -8.1‰ to -4.2‰ and a $\delta^{13}C_{ap}$ range of -9.5‰ to -6.5‰, indicating a reasonable amount of heterogeneity between $\delta^{18}O$ values within both male and female groups within the Fénix population.



Figure 5.16 Mean stable carbon and oxygen isotopic results comparing males and females during the mid-late Archaic Period for the Fénix Archaeological Complex.

- = Males (6 individuals)
- ▲= Females (8 individuals)

The 0.0‰ difference in $\delta^{13}C_{ap}$ values between males and females in the sample population is not statistically significant (t= 0.0, 0.4 > p > 1.0000). Additionally, the 0.2‰ difference in δ^{18} O values, between males and females in the sample population, is also not statistically significant (t= 0.3, 0.7 > p > 0.7672).

Mid-Late Archaic Period (c. 6000-2200 BP): Adults vs. Sub-Adults

Mean isotopic values for adults within the mid-late Archaic Period Fénix population were $-5.9 \pm 1.2\%$ for δ^{18} O and $-8.1 \pm 0.7\%$ for $\delta^{13}C_{ap}$, with a δ^{18} O range of -8.1% to -4.2% and a $\delta^{13}C_{ap}$ range of -9.5% and -6.5%. Mean values for sub-adults were $-6.3 \pm 1.4\%$ for δ^{18} O and $-6.6 \pm 1.8\%$ for $\delta^{13}C_{ap}$, with a δ^{18} O range of -8.3% to -4.7% and a $\delta^{13}C_{ap}$ range of -8.0% to -4.5% (Figure 5.17).



Figure 5.17 Mean results comparing adult to sub-adult stable carbon an oxygen isotope values during the mid-late Archaic Period at the Fénix Archaeological Complex.

- •= Adult (13 individuals)
- ▲= Sub-adult (7 individuals)

Furthermore, the 1.5‰ difference in $\delta^{13}C_{ap}$ values between adults and subadults in the mid-late Archaic Period sample population is considered to be statistically significant (t= 3.5, 0.4 > p > 0.0023). However, the 0.7‰ difference in δ^{18} O values, between adults and sub-adults in the sample population, is not considered to be statistically significant (t= 1.2, 0.6 > p > 0.2662).

Early Ceramic Period (c. 2200-1000 BP): Males vs. Females

Mean $\delta^{13}C_{ap}$ and $\delta^{18}O$ isotopic values for females within the Early Ceramic Period sample set were -6.3 ± 0.6‰ for $\delta^{18}O$ and -7.9 ± 0.9‰ for $\delta^{13}C_{ap}$, with a $\delta^{18}O$ range of -7.2‰ to -5.4‰ and an $\delta^{13}C_{ap}$ range of -9.8‰ and -6.7‰ (Figure 5.18). Average values for males within the population were -6.5 ± 0.9‰ for $\delta^{18}O$ and -7.9 ± 0.8‰ for $\delta^{13}C_{ap}$, with a $\delta^{18}O$ range of -8.0‰ to -5.0‰ and a $\delta^{13}C_{ap}$ range of -9.7‰ and -6.1‰.



Figure 5.18 Mean stable carbon and oxygen isotopic results comparing males and females during the Early Ceramic Period for the Fénix Archaeological Complex.

- = Males (15 individuals)
- ▲= Females (12 individuals)

The 0.0‰ difference in $\delta^{13}C_{ap}$ values between males and females in the Early Ceramic Period sample population is not statistically significant (t= 0.0000, 0.3 > p > 1.0000). Additionally, the 0.2‰ difference in δ^{18} O values, between males and females in the sample population is also not statistically significant (t= 0.5, 0.3 > p > 0.6033).

Early Ceramic Period (c. 2200-1000 BP): Adults vs. Sub-Adults

Average stable oxygen and carbon isotopic values for adults within the Early Ceramic Period population were -6.4 ± 0.8‰ for δ^{18} O and -7.9 ± 0.9‰ for $\delta^{13}C_{ap}$, with a δ^{18} O range of -7.9‰ to -4.9‰ and a $\delta^{13}C_{ap}$ range of -9.8‰ to -6.1‰. Mean values for sub-adults were -7.1 ± 0.8‰ for δ^{18} O and -7.3 ± 1.3‰ for $\delta^{13}C_{ap}$, with a δ^{18} O range of -8.7‰ to -5.7‰ and a $\delta^{13}C_{ap}$ range of -8.5‰ to -5.1‰ (Figure 5.19).



Figure 5.19 Mean results comparing adult to sub-adult stable carbon an oxygen isotope values during the Early Ceramic Period at the Fénix Archaeological Complex.

- = Adult (34 individuals)
- ▲= Sub-adult (9 individuals)

Furthermore, the 0.6‰ difference in $\delta^{13}C_{ap}$ values between males and females in the Early Ceramic Period sample population is not statistically significant (t= 1.6, 0.4 > p > 0.1275). However, the 0.7‰ difference in δ^{18} O values, between adults and sub-adults in the sample population, is statistically significant (t= 2.5, 0.3 > p > 0.0198).

Late Intermediate Period (c. 1000-550 BP)

There is only one Late Intermediate Period skeletal sample, therefore δ^{18} O results for this temporal period cannot be compared during this period.

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) Results

Overview

Results for the Sr/Ca, Ba/Ca and U/Ca elemental ratios from 37 skeletal samples from the Fénix Osteological Collection are compared with previous stable oxygen and nitrogen isotope results from this research (Table 5.4), to address questions about trophic level and post burial diagenesis.

ID	Sr/Ca	Ba/Ca	U/Ca	δ ¹⁸ 0 (ap)	δ ¹⁵ N (col)
F2-E2	0.006163366	0.0008168320	0.00001002480	-5.69	8.9
F3-E3	0.001421767	0.0003429390 0.00001002620		-6.39	13.7
F3-E4	0.002746862	0.0000911674	0.00000232063	-4.58	12.3
F3-E6	0.003121998	0.0001988470	0.00000766090	-6.94	10.8
F3-E7	0.004664144	0.0002686850	0.00000886944	-5.45	7.0
F3-E9	0.003504960	0.0001650920	0.00000738545	-8.09	14.3
F3-E10	0.000942057	0.0000926146	0.00000406792	-7.91	14.2
F3-E12	0.002159524	0.0000773810 0.00000170000		-6.73	10.9
F3-E13	0.002714728	0.0002039020 0.00000187961		-6.32	11.9
F3-E16	0.001039145	0.0000770893	0.00000287464	-	12.9
F3-E19	0.002000471	0.0001167330 0.00000253707		-8.32	-
F3-E20	0.002598331	0.0001275330	0.00000617402	-8.66	9.9
F3-E23	0.002343266	0.0001656730	0.00000302980	-5.53	12.9
F3-E27	0.004189733	0.0001764850	0.00000333333	-5.36	11.1
F3-E28	0.002524226	0.0001271570	0.00000282439	-7.95	11.4
F3-E33	0.002459210	0.0001269800	0.00000536770	-6.26	12.8
F3-E35	0.003810208	0.0017972680	0.00001214950	-6.13	14.0
F3-E37	0.001044244	0.0001070410	0.00000145338	-7.38	13.4
F3-E44	0.003065780	0.0003015910	0.00000558062	-5.89	11.4
F3-E45	0.002765304	0.0004183410	0.00000909950	-6.55	13.0
F3-E47	0.004454179	0.0002836850	0.00000599100	-5.59	13.8
F3-E48	0.001749341	0.0001468970	0.00000299065	-7.33	8.3
F3-E50	0.002696254	0.0001197800	0.00000293725	-7.15	11.1
F3-E53	0.003062006	0.0002178600	0.00000445296	-6.31	13.2
F3-E55	0.001578697	0.0001062770	0.00000273419	-5.85	14.5
F3-E56	0.001121606	0.0000739079	0.00000156316	-6.66	9.1
F3-E57	0.001196297	0.0001174930	0.00000460954	-6.35	10.0
F3-E60	0.003315952	0.0000997867	0.00000391088	-6.20	13.3
F3-E63	0.002326675	0.0000996475	0.00000660400	-6.22	-
F3-E64	0.002476258	0.0001398390	0.00001189460	-4.65	16.1
F3-E65	0.002541757	0.0007746310	0.00000798838	-6.82	14.5
F3-E67	0.002897795	0.0001833060	0.00000803889	-6.54	10.0
F3-E69	0.000885122	0.0000614407	0.00000353343	-8.06	14.7
F8-E2	0.003412604	0.0001697980	0.00000190250	-7.00	9.5
F8-E4	0.002959598	0.0002000960	0.00000236672	-7.52	10.6

Table 5.4 Summaries of Sr/Ca, Ba/Ca and U/Ca elemental ratios and δ^{18} O and δ^{15} N isotopic values for human bone from the Fénix Archaeological Complex.

F8-E5	0.002914191	0.0002724030	0.00000437366	-7.41	9.6
F12-E1	0.001218130	0.0002296980	0.00000557129	-7.23	11.4

Sr/Ca Elemental Results

Sr/Ca elemental ratios sit between 0.006163366 (F2-E2) and 0.000885122 (F3-E69), with most of the values clustering between 0.001 and 0.005 for the population sample (Figure 5.20). However, one outlier (F2-E2) sits higher than the other samples, with a value of 0.0062.



Figure 5.20 Sr/Ca elemental ratios plotted against stable nitrogen isotope values for individuals from the Fénix Archaeological Complex.

Ba/Ca Elemental Results

Ba/Ca values generally sit between 0.00006 and 0.0004 respectively for the sample population from the Fénix Archaeological Complex. Ba/Ca elemental ratios are relatively homogenous for the population sample, with only three outliers demonstrating higher Ba/Ca values (F3-E35, F2-E2 and F3-E65).



Figure 5.21 Ba/Ca elemental ratios plotted against stable nitrogen isotope values for individuals from the Fénix Archaeological Complex.

U/Ca Elemental Results

U/Ca ratios plotted against the δ^{18} O isotope values for the Fénix Archaeological Complex demonstrate values sitting between 0.000000803889 (F3-E67) and 0.0000121495 (F3-E35) (Figure 5.21).



Figure 5.22 U/Ca elemental ratios plotted against stable oxygen isotope values for the Fénix Archaeological Complex.

The U/Ca ratios demonstrate a relative amount of heterogeneity within the sample set from the Fénix Archaeological Complex.

Radiocarbon Dating Results

Overview

The radiocarbon dating results from direct dating of six skeletal samples (OZT171–OZT176) from the Fénix Archaeological Complex demonstrated uncalibrated dates ranging between 4865 and 1110 BP (Bertuch 2016) (Table 5.5).

Table 5.5 Radiocarbon dates, bone quality indicators and estimated percent marinecontribution to bone collagen samples from the Fénix Archaeological Complex (seeBertuch 2016). Radiocarbon calibration courtesy of Tiago Attorre.

Sample/Site ID (Material)	Lab ID	Bone N%	Collagen Yield (%)	Collagen C:N Ratio	Marine Diet (%)	Radio- carbon Age (yr BP)	SD	δ ¹³ C (‱ VPDB)	Cal Age (cal BP) 2 0
F2-E1 (Bone)	0ZT171	3.5	8.6	3.2	17	1805±25	25	-18.2	1522- 1698
F3-E2 (Bone)	0ZT172	2.5	5.4	3.2	33	2630±25	25	-16.4	2349- 2684
F3-E17 (Bone)	0ZT173	3.5	9.3	3.2	59	1110±25	25	-13.4	557- 775
F3-E31 (Bone)	0ZT174	3.7	10.8	3.2	23	2170±25	25	-17.5	1883- 2052
F3-E68 (Bone)	0ZT175	2.8	4.6	3.2	61	4865±30	30	-13.2	4921- 5315
F8-E3 (Bone)	0ZT176	2.7	7.1	3.2	18	1740±30	30	-18.0	1404– 1575

Calibrated radiocarbon dates ranged from 5315–557 BP, indicating that the Fénix Archaeological Complex was occupied from the Late Archaic Period through to the end of the Late Intermediate Period (c. 6000–550 BP) (Figure 5.22).



Figure 5.23 Graph showing the radiocarbon dated samples within the relative central Chilean chronological periods. Graph courtesy of Tiago Attorre.

Chapter Summary

This chapter summarises the results from the stable isotope and elemental analyses, and radiocarbon dating undertaken on human skeletal material from the Fénix Archaeological Complex. These results are discussed further in both a regional and global context in the Discussion Chapter of this thesis.

CHAPTER SIX: DISCUSSION

Overview

This chapter discusses the isotopic and elemental results of this research, with reference to the archaeology of the area and the relevant literature. In order to contextualise the results and place them in both local and broader settings. The discussion chapter is split into four sections in order to allow a clear view of the results and interpretations.

The first section presents a discussion of the overall results from the stable carbon, nitrogen and oxygen isotopic analyses from the population at the Fénix Archaeological Complex, with reference to the archaeological evidence and relevant global literature. This section aims to place the research into a global context and compare the δ^{13} C, δ^{15} N and δ^{18} O results with the archaeological site data.

The second section examines the stable carbon, nitrogen and oxygen isotope results with reference to other central Chilean sites and the relevant literature. This section aims to place the results into a regional context and answer questions on an inter-site level.

The third section discusses the stable carbon, nitrogen and oxygen isotope results on an intra-site level. This section breaks the site results down and discusses them in relation to each other, allowing a more in-depth analysis of the subsistence methods of the population at the site.

Lastly, the fourth section discusses the elemental results and the radiocarbon dating of the site. This part of the discussion chapter aims to examine the potential for elemental analysis to assess human diet and post-burial diagenesis, and to provide further contextual data for the chronology of the Fénix Archaeological Complex.

Before discussing the results, it is important to return to the primary research question presented in the introduction chapter of this thesis. The overall aim of this research was to conduct an isotopic and elemental analysis of skeletal samples from the population at the Fénix Archaeological Complex to examine long-term diet and mobility of this mid-late Holocene pre-Colombian central Chilean population. The primary question for this research was:

'What do stable carbon, nitrogen and oxygen isotope analyses of human skeletal material allow us to infer about changes and/or continuities in the diet and mobility of the populations at the Fénix Archaeological Complex (c. 7000–550 BP) in coastal central Chile, during the mid-late Holocene?'

In addition to the primary research question were a series of subsidiary questions which aimed to support a comprehensive examination of the lifeways of the Fénix Archaeological Complex population. In sum, this chapter contributes to the discussion about hunter-gatherer adaptive strategies, marine versus terrestrial resource use and the introduction of maize-based agricultural resources in central Chile.

Overall Discussion of Results

Overview

This section of the discussion chapter examines the stable carbon, nitrogen and oxygen isotope results from the Fénix Archaeological Complex and compares them to the archaeological, osteological, floral and faunal evidence from the site, enabling an investigation of the research questions. Stable carbon, nitrogen and oxygen isotope results for the population at the Fénix Archaeological Complex are also compared to baseline values and archaeological evidence on a global level in order to place the research into a global context.

Stable Carbon and Nitrogen Isotope Discussion

Stable carbon and nitrogen isotope values from the Fénix Archaeological Collection were compared to baseline values obtained from plants and animals in central Chile. As a whole, mean stable carbon and nitrogen isotope values for the Fénix Archaeological Complex population reveal a mixed diet of C₃, C₄ and low-high trophic level marine foods. These results are as expected for a population living on the coast in a temperate

environment, with no significant aridity or major climatic fluctuations (see Jenny et al. 2003; Montecinos and Aceituno 2003; Sanhueza 2013; Villa-Martínez and Villagrán 1997). Conversely, there is pronounced heterogeneity within the population, demonstrating a range of values, from individuals with values suggesting a high dependence on C_3 terrestrial resources to individuals with values approaching those of a predominant C_4 resource (maize) consumption, and individuals with values closer to those for the consumption of marine resources from mid-upper trophic levels.

Average stable carbon bone collagen ($\delta^{13}C_{col}$) values at the Fénix Archaeological Complex indicate that the population was likely generally consuming a mix of terrestrial resources. Furthermore, mean stable carbon apatite ($\delta^{13}C_{ap}$) values from the population at the Fénix Archaeological Complex are enriched ($\delta^{13}C_{ap}$, -7.8) compared to other central Chilean populations (see Falabella et al. 2007; Sanhueza and Falabella 2010), indicating a mixed C₃ and C₄ overall diet. Additionally, stable carbon isotope collagen to apatite (col-ap) spacing for the population at the Fénix Archaeological Complex is pronounced, with a range of 6.4‰ to 14.8‰. Large collagen to apatite spacing is usually indicative of a vegetarian diet, however, δ^{15} N values do not correlate with this as they indicate that the population was eating either wild herbivores or marine foods from low-mid trophic levels.

The isotopic results accord well with the archaeological evidence in coastal central Chile, which has suggested that the central coast was occupied from the early Archaic Period (c. 8800 BP) by groups of terrestrial hunter-gatherers who eventually learned to exploit coastal resources (see Falabella and Planella 1991; Falabella et al. 2007; Hermosilla et al. 2003; Planella 2005; Planella and Stehberg 1997; Sanhueza and Falabella 2010:127).

Marine resource consumption is variable throughout the population with $\delta^{15}N$ values indicating the consumption of marine foods from lower trophic levels (such as mollusks), through to marine foods from mid-upper trophic levels (such fish and marine mammals). These results match some of the archaeological remains from excavations at the site, which found evidence of many types of shellfish, including mussels (*Mytilidae* sp.), clams (*Mesodesma donacium, Siliqua patula* and *Veneridae* sp.), snails (*Tegula atra, Concholepas concholepas* and *Fisurella* sp.), sea urchins (*Loxechinus* sp.) and chitons (*Chiton* *magnificus*); fish such as the Chilean croaker (*Cilus gilberti*) and the Pacific jack mackerel (*Trachurus symmetricus*); and sea lions (*Otaria* sp.) (see Galarce and Santander 2011:44). Conversely, throughout the sample set there is minimal isotopic evidence for the consumption of marine foods from upper trophic levels, with most of the population clustering predominantly around the low-mid trophic level range.

Average δ^{15} N results for the population also indicate the consumption of marine mollusks, coinciding with osteological evidence from individuals at the Fénix Archaeological Complex. Nine out of the 73 individuals show signs of ear osteomas (auditory exostosis), which has been linked to diving for the collection of shellfish in past research (see Aufderheide and Rodríguez-Martín 1998; Hutchinson et al. 1997; Kennedy 1986; Okomura et al. 2007; Roberts et al. 2013; Standen et al. 1997).

Marine Resource Use at the Fénix Archaeological Complex

Overall, the Fénix Archaeological Complex reveals the consumption of marine resources from the middle Archaic Period (c. 7000–2200 BP) to the Late Intermediate Period (c. 1000–550 BP), demonstrating the continued consumption of marine resources throughout the Holocene. Additionally, $\delta^{13}C_{col}$ and $\delta^{15}N$ values coincide with the archaeological evidence found at the site and reflect a highly heterogenous population, with varied consumption of marine and terrestrial resources, comparable to those found globally.

Variable marine resource consumption over time can be seen throughout the world in places such as Europe, where Mesolithic-Neolithic transitions reflected a shift from a predominantly marine-based diet to a more terrestrial based diet (see Fischer et al. 2007; Liden 1995; Lubell et al. 1994; Price et al. 2007; Richards et al. 2003; Schulting 2011; Tauber 1981, 1986). Furthermore, populations such as those at Pendimoun in southern France, Samari in Italy, the sambaquis of Brazil, and the site of Huaca Prieta in Peru demonstrate the continued consumption of marine resources throughout the Holocene (see Dillehay 2008; Dilleyhay et al. 2012a, 2012b; Gaspar et al. 2008; Giorgi et al. 2005; Le Bras-Goude et al. 2006). These examples serve to demonstrate that while there have been general increases and decreases in marine resource use around the globe, there has

been no unilinear direction for the use of marine resources for all populations across the globe.

Stable carbon and nitrogen isotopic evidence has contributed further information about marine resource use that can be cross-referenced with archaeological data. Evidence of this has been seen at the sites of Molle Pampa in the Lluta Valley of northern Chile (approximately 25–30 km from the Pacific coast), where marine resources were being used to a greater extent than the archaeological remains suggested late in prehispanic times (see Aufderheide and Santoro 1999). Moreover, at the coastal sites of Caleta Vitor in northern Chile, isotopic values demonstrated the retention of hunter-gatherer economies with a high reliance on marine resources since the early Archaic period (see Roberts et al. 2013; Santoro et al. 2017).

Terrestrial Resource Use at the Fénix Archaeological Complex

Evidence of the consumption of terrestrial resources at the Fénix Archaeological Complex is reflected in the δ^{13} C and δ^{15} N isotopic signals. Stable carbon and nitrogen isotopic values indicate that 22 individuals from the population have values suggesting high consumption of terrestrial fauna. Faunal remains at the Fénix Archaeological Complex correspondingly include evidence of terrestrial fauna, such as camelids (*Lama guanicoe*), and lacustrine fauna, such as frogs (*Caudiverbera caudiverbera*) and rodents (*Myocaster coipus*) (see Galarce and Santander 2011:44). Additionally, three individuals (F3-E17, F3-E57 and F3-E58) have values closer to those of C₄ cultigens, indicating the regular consumption of C₄ based resources (maize). Other members of the population consumed varying degrees of C₄ based resources, as indicated by middle values signalling a mixed C₃-C₄ diet.

Stable δ^{13} C and δ^{15} N isotopic studies conducted in North America have illustrated the adoption of maize-based agricultural practices, with the increased consumption of maize over time (see Rose 2008). Additionally, populations in Central and South America, such as Lamanai in Belize, La Florida in Ecuador, and the Andes of Peru have demonstrated δ^{13} C and δ^{15} N values with variable emphasis on maize between sexes and ages. It is believed that these values were likely linked to status within the societies, with men generally consuming more maize than women and the elite having better dietary

variability than the non-elite (see Hastorf 1985; Somerville et al. 2012; Ubelaker et al 1995; White and Schwarcz 1989).

Stable carbon and nitrogen isotopic results for the Fénix Archaeological Complex population do not reflect the variable consumption of C₄ cultigens during all time periods. The slight increase in C₄ resource consumption during the Late Intermediate Period (c. 1000–550 BP) is not skewed toward a particular sub-group. The adoption of agricultural practices began in central Chile during the late Archaic Period (c. 6000–2200 BP) with the domestication of wild C₃ plants, such as quinoa (*Chenopodium quinoa*). Plant domestication continued through the Early Ceramic Period (c. 2200–1000 BP) with the introduction of C₄ cultigens, such as maize (*Zea mays*) gaining importance during the Late Intermediate Period (c. 1000–550 BP) (see Falabella et al. 2007, 2008; Sanhueza and Falabella 2010; Sanhueza et al. 2003). Moreover, archaeological evidence of floral remains at the Fénix Archaeological Complex include, the coquito palm (*Jubaea chilensis*) and the peumo (*Cryptocarya alba*) (see Galarce and Santander 2011. However, there is a lack of palaeobotanical evidence at the site for maize or any other cultigens.

The large collagen to apatite spacing for the population at the Fénix Archaeological Complex indicates that the population were likely primarily vegetarian or eating low fat and low protein resources (see Ambrose 1992; Krueger and Sullivan 1984; Lee-Thorp et al. 1989). However, this does not correlate with the δ^{15} N values, as they are indicative of at least some terrestrial and marine protein in the diet. The mechanisms for this so far remain uncertain and will be discussed later in this chapter.

Stable Oxygen Isotope Discussion

Overview

Stable oxygen isotope values from the Fénix Archaeological Collection were compared to baseline water values ($\delta^{18}O_{SMOW}$) for central Chile. Central Chile has the advantage of having distinct $\delta^{18}O_{SMOW}$ signals for its different geographic areas, owing to the variable geography of the landscape (coasts, valleys and mountains) within a narrow east to west

strip (see Falabella et al. 2007; Moser 1972; Sanhueza and Falabella 2010). Groundwater variation, resulting from changes in temperature and altitude between the coasts, valleys and highlands, provides great variation in the $\delta^{18}O_{SMOW}$ values for each landscape (see Jenny et al. 2003; Montecinos and Aceituno 2003; Moser 1972; Sanhueza and Falabella 2010). Additionally, this variable geography allowed for different resources in each area and was therefore amenable to highly mobile populations.

Landscape Use and Mobility at the Fénix Archaeological Complex

Landscape use and mobility reflected in the mean δ^{18} O values for individuals from the Fénix Archaeological Complex, suggest heterogeneity within the populations, indicating that individuals were likely moving across the landscape, as δ^{18} O values fall between those for coastal ($\delta^{18}O_{SMOW}$, -3.5‰) and valley ($\delta^{18}O_{SMOW}$, -8.5‰) areas (see Falabella et al. 2007; Knudson 2009, 2012; Sanhueza and Falabella 2010).

Stable oxygen isotope results, cross-referenced with the stable carbon and nitrogen isotope results, both reveal heterogeneity within the population. Stable oxygen isotope results support a mobile population, which may help to explain the variability within the δ^{13} C and δ^{15} N values, as those travelling between different areas would have diverse δ^{13} C and δ^{15} N isotopic values from consuming differential resources along the way.

Overall, stable oxygen isotope analysis of the population at the Fénix Archaeological Complex show $\delta^{18}O_{SMOW}$ values from both the coastal area and valley areas, reflecting a highly mobile population, with $\delta^{18}O$ values indicating that members of the population were travelling between the interior and the coast. Due to the variability of the $\delta^{18}O$ values, it is difficult to tell whether certain members of the population were actually foreigners to the burial population, or if they were merely travelling between regions and were buried on the coast. An isotopic analysis of dental samples from the population may shed light on whether individuals were born at the site and travelled between the coast and interior, or whether they were born elsewhere and ended up on the coast later in life. Further research into this area will allow interpretations about whether some individuals within the population were more mobile than others.

Inter-Site Discussion

Overview

This section of the discussion chapter investigates the stable carbon, nitrogen and oxygen isotopic results in comparison to other local central Chilean isotopic studies. The aim of this section is to place the results into a regional context and answer the research questions at an inter-site level, with reference to the relevant literature.

Stable Carbon and Nitrogen Isotope Results

Stable carbon and nitrogen isotopic composition of bone collagen and apatite from the population at the Fénix Archaeological Complex was compared to other central Chilean archaeological sites, as well as known central Chilean human population values representing diets at the extremes of the $\delta^{13}C_{col}$ and $\delta^{15}N$ spectrum (C₃ farmers, C₄ maize farmers, and marine hunters).

The valley site of Valle Verde in central Chile is representative of a dietary end-point representing a 100% C_3 terrestrial diet (see Roberts et al. 2013:2367). The Fénix Archaeological Complex population demonstrates values that do not match with those of a completely C_3 terrestrial diet, due to isotopic values indicating the consumption of some C_4 resources and elevated nitrogen levels indicating the inclusion of marine resources in the diets of the population at the site.

Similarly, the valley site of Maria Pinto has less negative $\delta^{13}C_{col}$ values and is thought to represent a population with a mixed diet of C₃–C₄ and lower trophic level marine foods. (see Falabella et al. 2008). While the population at the Fénix Archaeological Complex were likely consuming some C₄ resources, stable carbon and nitrogen isotopic values do not suggest a heavily C₄ related diet or the adoption of maize-based agricultural practices.

Furthermore, while the valley site of Molle Pampa Medio is located in northern Chile, it has been generally taken to be representative of an 80–100% marine diet, giving a dietary endpoint to compare other samples to (see Roberts et al. 2013; Tykot et al. 2009). The overall isotopic values from the Fénix population sit roughly between those for marine

hunters and C₃ European farmers but do not directly coincide with either, due to having a mixed terrestrial diet containing lower trophic level marine foods.

A comparison of the $\delta^{13}C_{col}$ and $\delta^{15}N$ values to individuals from the highland site of Chacayes was also conducted in order to provide geographic variability within the sample set. The site of Chacayes demonstrates stable carbon and nitrogen isotopic values similar to those for consumers of a mixed terrestrial diet. A comparison between the population of the Fénix Archaeological Complex and the individuals from the highland site demonstrates similar $\delta^{13}C_{col}$ values but different $\delta^{15}N$ values, due to the lack of marine resource consumption for the Chacayes individuals.

Coastal central Chilean sites, such as Las Brisas 3, Las Brisas 10-14, LEP-C and Cancha de Golf 1, Concon, Pupido and S-Bato 1 provide the most comparable $\delta^{13}C_{col}$ and $\delta^{15}N$ values to the Fénix Archaeological Complex population, with similar nitrogen values and varied carbon values (see Falabella et al. 2007; Swift et al. 2017). These sites demonstrate populations that were eating mixed C₃ and C₄ terrestrial resources as well as a minor contribution of marine resources from lower trophic levels (see Falabella et al. 2007; Sanhueza and Falabella 2010; Swift et al. 2017).

As mentioned in the literature review section of this thesis, much of the coast of central Chile provides access to rich marine and lacustrine resources (see Falabella et al. 2007; Galarce and Santander 2011; Sanhueza and Falabella 2010; Santoro et al. 2005). Therefore, it has been assumed that Chilean coastal populations would have been heavily exploiting marine resources (see Falabella et al. 2007; Galarce and Santander 2011; Sanhueza and Falabella 2010). However, stable carbon and nitrogen isotopic results from other central Chilean coastal sites, such as LEP-C, Cancha de Golf 1 and Las Brisas 10-14, indicate that the sampled individuals were not consuming marine resources to any significant extent (see Falabella et al. 2007; Sanhueza and Falabella 2010). One possible reason for this could be that central Chilean populations had access to rich terrestrial resources and therefore did not need to rely as heavily on marine resources as those living in more extreme environments, such as northern Chile (see Petruzzelli et al. 2012; Roberts et al. 2103).

While $\delta^{15}N$ values from the Fénix population do not indicate the intensive exploitation of marine resources that can be seen in northern Chile, the population at the Fénix Archaeological Complex has more positive overall $\delta^{15}N$ values when compared to coastal, valley and highland sites in central Chile, indicating that they were likely consuming more marine resources from low-mid trophic levels than other local populations (see Falabella et al. 2007; Sanhueza and Falabella 2010; Swift et al. 2017).

One reason for this difference in marine resource consumption, may be that the sample set from the Fénix Archaeological Complex is far larger than that of other sites in central Chile, providing more variability within the sample set. Another reason for this may be that the population at the Fénix Archaeological Complex contains more mid-late Archaic individuals than any other single site sample set in central Chile. More isotopic studies on larger and earlier sample sets from the surrounding central Chilean sites will allow further conclusions to be drawn about the consumption of marine resources at other central Chilean coastal sites.

The above comparison of the mean stable carbon and nitrogen isotopic results from the Fénix Archaeological Complex, demonstrates geographic similarities and differences between the diets of prehistoric central Chilean populations. The data from Fénix adds a wealth of information about the diets of the prehistoric inhabitants of this coastal site and allows for further analysis of stable carbon and nitrogen isotopes on a local level.

Stable Oxygen Isotope Results

Stable oxygen isotopic results from the Fénix Archaeological Complex were compared to coastal, valley and highland sites in central Chile. Stable oxygen isotope results indicate that the Fénix population sits between values from coastal sites (such as LEP-C, Cancha de Golf 1 and Las Brisas 10-14) and valley/highland sites (such as Valley Verde, El Mercurio and Chacayes).

Sites, such as LEP-C, Cancha de Golf 1 and Las Brisas 10-14 demonstrate stable oxygen isotope values coinciding with those for coastal habitation, with limited movement inland. Furthermore, sites such as Valle Verde, El Mercurio and Chacayes demonstrate disparate δ^{18} O signals corresponding with those for the lowland valley areas, with

movement through different regions. The population at the Fénix Archaeological Complex demonstrates δ^{18} O values between the coastal site of Las Brisas 10-14 and the highland site of Chacayes. These values coincide with those for individuals moving between the coast and the interior. However, it is relevant to note that the population sample size at the Fénix Archaeological Complex is much higher than for any other single site in central Chile and may therefore skew the results to make the population seem more mobile than other populations with smaller sample sets. Further stable oxygen isotope studies on surrounding sites will clarify these results.

Intra-Site Discussion

Overview

This part of the discussion chapter examines the stable carbon, nitrogen and oxygen isotopic results on an intra-site level. This section examines individual values from the population of the Fénix Archaeological Complex and compares them against each other and the relevant literature. This part also splits the site results into site groups (e.g. Fénix 2, 3, 8 and 12), temporal groups (Archaic vs. Early Ceramic etc.), sex groups (female vs. male) and age groups (adult vs. sub-adult). A comparison of these groups against one another allows a comprehensive examination and discussion of the diet and landscape use of the Fénix Archaeological Complex population.

The Fénix Archaeological Complex: Intra-Site Analysis

The Fénix Archaeological Complex is made up of different areas of excavated units (Fénix 2, Fénix 3, Fénix 8 and Fénix 12). These units are archaeologically defined but do not necessarily denote separate populations at the site (see Galarce and Santander 2011:9). The areas of Fénix 2, Fénix 3 and Fénix 8 are all within 200 m of each other, with most being less than a 50 m walk from the next excavation area (see Galarce and Santander 2011:9). However, the skeleton belonging to the Fénix 12 site is the furthest from the coast and is located approximately 2 km south of the other areas (Rebolledo 2011c).

Fénix 2

Stable carbon and nitrogen isotope analysis was conducted on two individuals (F2-E1 and F2-E2) sampled from the Fénix 2 site. Both of these individuals were dated to the Early Ceramic Period (c. 2200–1000 BP). Oxygen isotope analysis was only conducted on the F2-E2 individual due to restricted sample amounts.

Average stable carbon bone collagen values from Fénix 2 were -18.1‰ suggesting predominantly C_3 based resource consumption. Overall $\delta^{13}C_{ap}$ values were depleted, sitting at -8.4‰, suggesting the addition of C₄ based resources. Furthermore, the carbon to apatite spacing of 9.0‰, suggests the consumption of predominantly vegetarian foods (see Tykot et al. 2009). However, mean stable nitrogen isotope values for Fénix 2 were 9.5‰, indicating the consumption of wild herbivores.

Stable oxygen isotope results for the individual sampled from Fénix 2 (F2-E2) demonstrate values (δ^{18} O, -5.7‰) between those for coastal and valley waters (δ^{18} O_{SMOW}, -3.5‰ to -8.5‰), indicating that the individual was likely travelling around the coastal region, with intermittent valley water consumption.

Fénix 3

The site of Fénix 3 demonstrates stable carbon and nitrogen isotope results for 60 individuals, illustrating the largest range of isotopic values at the Fénix Archaeological Complex. The site also spans all three time periods, from the mid-late Archaic (c. 7000–2200), through to the Late Intermediate Period (c. 1000–550 BP).

Stable carbon isotopic results for bone collagen from the site of Fénix 3, have a wide range of values demonstrating the variability in subsistence strategies over time and throughout the population. Based on previous dietary ranges for 100% C₃ resource contribution ($\delta^{13}C_{col}$, -20.1%₀ ± 2.9) and 100% C₄ resource contribution ($\delta^{13}C_{col}$, -4.7%₀), diets of the Fénix 3 population range from a high dependence on C₃ foods to a moderate C₄ resource contribution ($\delta^{13}C_{col}$, -20.5%₀ to -13.0%₀). Four individuals from the Fénix 3 site (F3-E7, F3-E14, F3-E48 and F3-E66) demonstrated depleted stable carbon collagen values ranging between -20.5%₀ and -20.1%₀, indicating values close to a 100% C₃ based diet. Conversely, three individuals (F3-E17, F3-E18 and F3-E58) all demonstrated

enriched $\delta^{13}C_{col}$ values, with ranges between -13.9‰ and -13.0‰, indicating the consumption of C₄ resources.

Mean $\delta^{13}C_{ap}$ values for the Fénix 3 population were -7.7‰ and collagen to apatite spacing for the Fénix 3 individuals is high, with values ranging between 6.4‰ and 14.8‰, with a mean of 9.3‰. High collagen to apatite spacing is usually indicative of a vegetarianbased diet or a diet with generally low fats and low protein (see Ambrose and Norr 1993; Lee-Thorp et al. 1989), however, the three individuals with the highest nitrogen values for the Fénix 3 population also demonstrated higher $\delta^{13}C_{col-ap}$ spacing (between 8.1‰ and 9.6‰).

Average δ^{15} N values for the Fénix 3 population sit at 12.3‰, indicating that the population as a whole was consuming a combination of wild herbivores and marine foods from lower trophic levels. However, due to the heterogeneity within the population, some members (F3-E58, F3-E59 and F3-E65) had higher nitrogen values (16.1‰–17.2‰) indicating the consumption of marine foods from higher trophic levels, such as fish and sea mammals. Moreover, some members (F3-E7, F3-E66 and F3-E14) of the population displayed lower nitrogen values (7.0‰–7.7‰), indicating the regular consumption of wild herbivores.

Mean stable oxygen isotope analysis values for 59 individuals from the Fénix 3 site are -6.3‰, suggesting that the population were travelling between the interior and the coast with values ranging from those closer to coastal values ($\delta^{18}O_{SMOW}$, -3.5‰) to those closer to valley signals ($\delta^{18}O_{SMOW}$, -8.5‰) (e.g., F3-E20 and F3-E61).

Individuals, such as F3-E4, F3-E24, F3-E36, F3-E41, F3-E51 and F3-E63 all have δ^{18} O values below -5.0‰ indicating that they likely didn't travel far from the coast, reflected by similar local coastal water values ($\delta^{18}O_{SMOW}$, -3.5‰). However, individuals such as F3-E19, F3-E20, F3-E28, F3-E61, F3-E64 and F3-E66 all have δ^{18} O values between -8.0‰ and -8.9‰, indicating that they spent a significant portion of the last 10 years of their lives consuming valley waters ($\delta^{18}O_{SMOW}$, -8.5‰) and were therefore either travelling between the coasts and valleys during their lives or were moved to the coast for burial after death.

Overall, δ^{13} C and δ^{15} N analysis of the Fénix 3 population indicates variability within the population, with some members of the population consuming predominantly C₃ resources, others consuming high trophic level marine resources and others with δ^{13} C values suggesting moderate to high consumption of C₄ resources. Stable oxygen isotope analysis of the population also indicates a range of values, with results reflecting a mobile population travelling between the interior valleys and coasts, which could also account for the dietary variability within the population.

Fénix 8

Stable carbon and nitrogen isotope results were obtained for all six individuals from the Fénix 8 site who were all relatively dated to the Early Ceramic Period (c. 2200–1000 BP). Average stable carbon collagen values for the population were -18.5‰ ($\delta^{13}C_{ap}$ -7.9‰) suggesting a primary consumption of C₃ foods, with the addition of C₄ based resources.

Carbon to apatite spacing for the Fénix 8 population is similar to that for the other Fénix populations, ranging between 9.8‰ and 11.5‰, indicating the consumption of a predominantly vegetarian diet or a diet based on low fats and low protein. However, mean δ^{15} N values for the population average at 9.5‰ suggesting that the population were regularly consuming wild herbivores. Furthermore, stable oxygen isotope values for five individuals from the site of Fénix 8 have mean δ^{18} O signals of -6.9‰, suggesting that the individuals were consuming waters from between the coasts and valleys, with a range of -5.9‰ to -7.5‰.

Overall, stable carbon, nitrogen and oxygen isotope results from the Fénix 8 population indicated that the population was moving between the inland valley areas and coastal areas and regularly consuming C_3 foods with the addition of C_4 based resources and protein from terrestrial sources.

Fénix 12

Stable carbon and nitrogen isotope analysis of the individual sampled from the Fénix 12 location indicates the consumption of C₃ resources, with the addition of marine resources from lower trophic levels. The $\delta^{13}C_{col}$ and $\delta^{15}N$ results for the individual from the Fénix

12 location fall within the middle range for the individuals from the Fénix Archaeological Complex sitting at -17.8‰ for $\delta^{13}C_{col}$ and 11.4‰ for $\delta^{15}N$. Additionally, $\delta^{13}C_{ap}$ values were -9.1‰, with a collagen to apatite spacing of 8.7‰, suggesting either a predominantly vegetarian diet or a diet generally consisting of low protein and low fats (see Ambrose and Norr 1993; Lee-Thorp et al. 1989).

Stable oxygen isotopic analysis of the individual found at the site of Fénix 12 were -7.2‰, which is similar to those of local valley waters ($\delta^{18}O_{SMOW}$, -8.5‰), signifying that the individual was consuming valley waters during the last ten years of their life before either dying on the coast or being brought to the coast after death.

Overall Sex Comparison: Males vs. Females

Mean stable carbon and nitrogen isotope values for males and females at the Fénix Archaeological Complex demonstrate similar values when compared against each other. Stable carbon isotopic values for both sexes indicate the consumption of C_3 terrestrial resources, with a minor contribution of C_4 resources.

Overall, males were consuming foods with a slightly higher nitrogen content (1.2‰), suggesting a marginally increased consumption of marine foods or factors related to physiological differences between the sexes (see Ambrose 1987; Rose 2008). Stable nitrogen isotope values between males and females are considered statistically distinguishable (according to unpaired t-testing), meaning that the difference is not just due to the vagaries of sampling, but indicates a "real" difference between the values within the population (Drennan 2009:155).

Average δ^{18} O results for males and females at the Fénix Archaeological Complex demonstrate very similar values, suggesting insignificant differences (according to unpaired t-testing) between sexes that were both were moving between the coasts and the valleys.

Overall Age Comparison: Adults vs. Sub-Adults

The mean δ^{13} C, δ^{15} N and δ^{18} O values for adults and sub-adults within the Fénix population indicate that both were consuming similar foods to each other and moving in Bianca Waldie 249 similar regions throughout the landscape. Results from significance testing suggest that the difference in values between stable carbon, nitrogen and oxygen isotopic results for adults and sub-adults within the population do not reflect a "real" difference.

Additionally, while there are mortuary contexts for the areas of Fénix 8 and Fénix 12, there are none for Fénix 3 and Fénix 2. Mortuary contexts for the first 48 individuals from the area of Fénix 3 were not recorded during excavation, therefore inferences about the status of individuals at the site cannot be made (see Rebolledo 2012a:52). Due to this, no assumptions about class/status differences were made about the Fénix Archaeological Complex population.

Fénix Archaeological Complex: Overall Temporal Comparison

Stable carbon and nitrogen isotopic results were split into three temporal periods: the mid-late Archaic Period (c. 7000–2200 BP), the Early Ceramic Period (c. 2200–1000 BP) and the Late Intermediate Period (c. 1000–550 BP) as per the relative dating at the site (see Galarce and Santander 2011). These periods all show slight differences in stable carbon, nitrogen and oxygen values for the population at the Fénix Archaeological Complex.

Mid-Late Archaic Period (c. 7000–2200 BP)

During the mid-late Archaic Period (c. 7000–2200 BP), the population at the Fénix Archaeological Complex demonstrated $\delta^{13}C_{col}$ and $\delta^{15}N$ values that were consistent with the consumption of mixed resources with the addition of marine resources from low-mid trophic levels. This correlates with the archaeological evidence, which suggests that Archaic Period populations in central Chile were primarily hunter-gatherers and would have been consuming slightly more marine resources than in later time periods (see Falabella and Planella 1991; Falabella et al. 2007; Hermosilla et al. 2003; Planella 2005; Planella and Stehberg 1997; Sanhueza and Falabella 2010).

Average $\delta^{15}N$ values from the population at the Fénix Archaeological Complex demonstrate the highest values out of the three time periods at the site, with $\delta^{15}N$ values dropping slightly during the Early Ceramic Period and then further during the Late Intermediate Period. These results indicate that the population at the Fénix

Archaeological Complex were consuming slightly more marine-based resources during the mid-late Archaic Period compared to other time periods. Two individuals (F3-E64 and F3-E59) from the late Archaic Period have $\delta^{15}N$ results indicating the consumption of marine resources from upper trophic levels (16.1‰ to 16.6‰). Additionally, only three mid-late Archaic Period individuals (F3-E12, F3-E14 and F3-E57) demonstrate $\delta^{15}N$ values that do not correspond to the consumption of marine resources, denoted by $\delta^{15}N$ values under 11.0‰ (see Schoeninger and DeNiro 1984).

During the mid-late Archaic Period, mean δ^{18} O results were less negative overall than for other time periods at the site, sitting between baseline water values for coastal and valley areas. These values indicate that the population were likely moving between the coast and the interior, though potentially not as much as in later time periods. This is in contrast with the archaeological evidence for hunter-gatherers, which instead indicates that the earlier populations would have been more mobile than later populations. However, Initial Early Ceramic Period (c. 2200–1750 BP) and Early Ceramic Period (c. 2200–1000 BP) populations still include cultures that maintained a hunter-gatherer lifestyle (e.g., the Bato culture), and mean population values are only slightly less negative meaning that the difference between the values is not necessarily indicative of a difference between subsistence methods.

Sex and Age Comparisons

Stable carbon and nitrogen isotopic values for males and females during the mid-late Archaic Period demonstrate very similar values to each other with both eating predominantly C₃ terrestrial foods with very minor inclusions of C₄ resources and marine foods from lower trophic levels. One male (F3-E14) and one female (F3-E12) are the only individuals during this time period that show values that do not indicate the consumption of marine based resources but are instead likely consuming terrestrial fauna. Additionally, mean δ^{18} O values for males compared to females during the mid-late Archaic Period do not demonstrate significant differences in values, meaning that one is not more mobile than the other (according to unpaired t-testing). Furthermore, results from the mid-late Archaic Period demonstrated a significant difference between $\delta^{13}C_{col}$ values for adults and sub-adults, with adults having more negative values than sub-adults, representing a slightly higher consumption C₃ resources.

Average, δ^{18} O values for the Fénix Archaeological Complex population during the midlate Archaic Period sit between those for coastal and valley waters (δ^{18} O, -6.0‰), representing the mobility of the population between the inland valleys and the coast.

Early Ceramic Period (c. 2200–1000 BP)

During the Early Ceramic Period the population at the Fénix Archaeological Complex demonstrated stable carbon and nitrogen isotopic results indicating a mixed diet of C_3 and C_4 resources, with the addition of marine resources from lower trophic levels and wild terrestrial herbivores.

Average $\delta^{13}C_{col}$ values for this time period were -17.2‰, with values as high as -20.5‰ and as low as -13.0‰, ranging between the consumption of close to 100% C₃ resources and a significant intake of C₄ resources. Average $\delta^{13}C_{col}$ values for the Early Ceramic Period are depleted compared to mid-late Archaic Period, likely due to the range of values within the sample sets (according to unpaired t-testing).

Average stable nitrogen values for the population during this time period are 11.5‰, indicating the consumption of marine foods from lower trophic levels. However, one individual (F3-E58) demonstrates enriched δ^{15} N values (17.2‰), indicating the consumption of high trophic level marine resources, such as marine mammals. Conversely, 19 out of 69 individuals demonstrate δ^{15} N values that do not correspond to marine values, but instead indicate the regular consumption of wild herbivores.

Cultural material remains at the Fénix Archaeological Complex for this time period indicate the presence of the Bato cultural complex, with a lack of material evidence for the Llolleo cultural complex (see Galarce and Santander 2011; Planella 2005; Planella et al. 2011; Sanhueza 2013). As mentioned in the background chapter, the Bato cultural complex demonstrates a diet associated with hunting and gathering, mixed resources with moderate marine intake and high mobility (see Falabella et al. 2007; Planella and

Falabella 1987; Sanhueza 2013). Conversely, the Llolleo cultural complex demonstrates a more sedentary lifestyle, participating in maize-related agricultural activities (see Falabella et al. 2007; Sanhueza and Falabella 2010).

Average stable oxygen isotope values for the Fénix Archaeological Complex population during the Early Ceramic Period sit at -6.5‰, demonstrating values between those for coastal and valley waters. Stable carbon, nitrogen and oxygen isotopic values during the Early Ceramic Period (c. 2200–1000 BP) coincide with the Bato cultural evidence found at the Fénix Archaeological Complex, as the values indicate a mobile population, that was consuming mixed terrestrial resources with moderate consumption of marine resources. However, the low to moderate consumption of C₄ resources, as indicated by individuals with enriched δ^{13} C values, is more consistent with that of the Llolleo cultural complex.

Sex and Age Comparisons

During the Early Ceramic Period, mean δ^{13} C and δ^{15} N values indicate statistically significant (unpaired t-test) differences between males and females. Males during the Early Ceramic Period show more positive δ^{15} N values and less negative $\delta^{13}C_{col}$ values, indicating a slightly higher consumption of marine resources and a more varied consumption of terrestrial resources.

A comparison of mean stable carbon and nitrogen isotopic values during the Early Ceramic Period, indicated insignificant differences (unpaired t-test) between adults and sub-adults, indicating that they both consumed very similar resources to each other during this time period.

Mean stable oxygen isotope results demonstrate very close values between males and females, indicating no real difference between the mobility of the two. Conversely, the (0.7‰) difference between δ^{18} O values for adults versus sub-adults is statistically significant and may indicate a higher level of mobility for adults, with δ^{18} O signals approaching those of valley ($\delta^{18}O_{SMOW}$, -8.5‰) values, meaning that both women and men spent a significant part of their adult life consuming waters from valley areas, before returning to the coast.

Late Intermediate Period (c. 1000-550 BP)

During the Late Intermediate Period (c. 1000–550 BP), mean δ^{13} C and δ^{15} N values from the Fénix site show a slight reduction in δ^{15} N values and enriched δ^{13} C values, suggesting the consumption of fewer marine foods and the moderate consumption of C₄ based resources. However, as there are only two individuals (F3-E17 and F3-E65) with heterogenous values for this time period, the sample set is not as representative as the previous two periods.

Isotopic evidence is associated with the cultural remains at the Fénix Archaeological Complex, which indicate the presence of the Aconcagua cultural group. Archaeological evidence for the Aconcagua cultural group is associated with a mix of hunter-gatherer and agricultural lifeways (see Galarce and Santander 2011; Politis 2003; Sanhueza 2013).

Furthermore, the Aconcagua cultural group were believed to have seasonal camps that moved between the coasts and inland valleys (see Cornejo 2010; Falabella et al. 2007; Hermosilla et al. 2003; Massone et al. 1998; Planella and Stehberg 1997). This correlates with the mean stable oxygen isotope values (δ^{18} O, -6.8‰) for the population during the Late Intermediate Period, which demonstrated marginally more negative δ^{18} O values than the previous two periods and are representative of mobility between the inland valley areas and the coastal Fénix Archaeological Complex.

Mean stable carbon, nitrogen and oxygen values could not be compared between the sexes during the Late Intermediate Period (c. 1000–550 BP), due to the small sample size of only two individuals and one being of an indeterminate sex. Differences in mean $\delta^{13}C_{col}$ and $\delta^{15}N$ values for adults versus sub-adults indicate higher $\delta^{15}N$ and more negative $\delta^{13}C_{col}$ than sub-adults. Additionally, as there was only one individual (F3-E65) analysed for stable oxygen isotope analysis, any comparisons between sex and age cannot be established. Due to the sample size in this population (two individuals, F3-E17 and F3-E65), information about the Late Intermediate Period population as a whole is not as representative as it is for the other time periods in this study. Thus, sex differences previously reported for this period (see Falabella et al. 2007), which demonstrated males consuming more maize than females could not be observed within the Fénix population.

Issues Impinging on Isotopic Interpretation in Central Chile

One of the main interpretive issues for this study was the estimation of the percentage of C_4 in the diets of the inhabitants from the Fénix Archaeological Complex. In order to estimate these percentages, the isotopic "endpoints" method was used. However, this method does not completely account for the exact values in the human diet as there is a hypothetical range of C_3 plant values that can move the "endpoint" baselines by as much as ±5% (Tykot et al. 2009:167). This means that the estimated percentage of C_4 in the diet could be up to 10% lower or 20% higher than the marked C_4 "endpoint" (see Tykot 2004; Tykot et al. 2009). In addition to this, because diet-bone apatite spacing cannot be experimentally determined accurately, estimating the actual percentage of C_4 in human bone apatite is limited, and maize consumption in bone collagen is underrepresented (Tykot et al. 2009:164). This poses a problem for estimating the amount of maize in a mixed C_3 – C_4 diet in central Chile. However, while a concise percentage was not recorded for the contribution of C_4 in the diets of the individuals at the Fénix Archaeological Complex, δ^{13} C values were still used to examine the presence of maize in the diets of the population, with rough estimates (e.g., low, moderate, high) being used in the text.

Additionally, enriched δ^{13} Ccol and δ^{13} Cap values were found for skeletal samples from the mid-late Archaic Period (c. 7000–2200 BP). Enriched δ^{13} C samples have often been interpreted as an indication of the consumption of C₄ based resources (see Falabella et al. 2007; Sanhueza and Falabella 20101: Tykot et al. 2009). To date, there is no archaeological evidence in central Chile for the consumption of maize during this period of time (see Falabella et al. 2007; Sanhueza and Falabella 2010:133). The Fénix Archaeological Complex also does not demonstrate archaeological or palaeobotanical evidence for the adoption of maize-based agricultural practices. However, there are a few explanations that may account for this discrepancy. The first is that the skeletal samples were relatively dated according to stratigraphy and ceramic presence or lack thereof. Therefore, it is possible that the dates for the skeletons are later than assigned, but until further radiocarbon dating is conducted, this will remain unclear.

The second explanation could be that the skeletal samples suffer from post-mortem diagenesis, which could skew the isotopic results. However, collagen contamination was Bianca Waldie 255

checked by measurement of the atomic C:N ratios and all ratios fell within the acceptable range of 2.8–3.6 (see Ambrose 1990; DeNiro 1985). Additionally, all skeletal samples used achieved a collagen yield of between 5 and 30% indicating good preservation (see Ambrose 1990).

Another interpretive issue in this research was that the isotopic results for δ^{13} C for samples such as F3-E66 reflect depleted $\delta^{13}C_{col}$ values and enriched $\delta^{13}C_{ap}$ values. One reason for the carbonate values increasing by a greater amount than the collagen values, may be that relatively small amounts of maize in the diet are reflected in the isotopic signature of bone apatite, but not in the isotopic signature of the bone collagen, due to $\delta^{13}C_{col}$ being biased towards the protein component of the diet and $\delta^{13}C_{ap}$ reading for the whole diet (see Ambrose et al. 2003; Fernandes et al. 2012; Harrison and Katzenberg 2003; Lee-Thorp et al. 1989). Therefore, when C₄ based resources (such as maize) are introduced into a C₃ based diet, it will be reflected in the $\delta^{13}C_{ap}$ values of the bone but not in the $\delta^{13}C_{col}$ signatures until it forms a significant portion of the diet (Harrison and Katzenberg 2003:242).

A final interpretive issue in this research was the large spacing between stable carbon collagen and apatite values. Past studies on collagen to apatite spacing have agreed that a spacing over +7‰ is indicative of a vegetarian diet for human consumers (see Fernandes et al. 2012; Krueger and Sullivan 1984; Lee-Thorp et al. 1989). However, the stable nitrogen values for the population at the Fénix Archaeological Complex are all between +7‰ and +17.2‰, indicating that the population were consuming a range of protein sources, from wild terrestrial herbivores to marine mammals from upper trophic levels. While the mechanisms for this remain unexplained, discrepancies between the $\delta^{13}C_{col-ap}$ spacing and the $\delta^{15}N$ values may contribute data to test theoretical proposals concerning the spacing between $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ values presented by past researchers (see Ambrose et al. 1997; Ambrose and Norr 1993; Harrison and Katzenberg 2003; Tieszen and Fagre 1993). Additionally, fluctuations and the general heterogeneity of the population may be explained by further examining post-burial diagenesis, which will be explored in this chapter through trace element analysis of uranium.

Overview

This section of the discussion chapter examines the results of the strontium, barium, calcium and uranium trace element analysis and the radiocarbon dating results. An analysis of strontium, barium and calcium ratios allows for further examination of the diet and trophic level of the population at the Fénix Archaeological Complex. Furthermore, uranium analysis aids in assessing the extent, if at all, of post-burial diagenetic contamination. Finally, radiocarbon dating results contribute to the chronological resolution at the Fénix Archaeological Complex.

Strontium (Sr/Ca) and Barium (Ba/Ca) Elemental Analyses

Elemental analyses of strontium (Sr/Ca) and barium (Ba/Ca) were employed in order to add a further element of information to the dietary reconstruction of the population at the Fénix Archaeological Complex. A combination of non-essential elements, such as strontium and barium, compared to that of essential elements with similar behaviour, such as calcium, can aid in reconstructing marine versus terrestrial resource use and trophic chains, through biopurification (see Burton and Price 1990; Peek and Clementz 2012). Trace element analysis of strontium, barium and calcium can identify dietary trends by an analysis of the biogenic amounts of each in the skeletal tissues.

Sr/Ca results for the population at the Fénix Archaeological Complex were all low sitting between 0.006163366 and 0.000885122). Additionally, Ba/Ca ratio results for the population at the Fénix Archaeological Complex were all also all very low, generally sitting between 0.00006 and 0.0004 indicating the consumption of high trophic level foods. Ba/Ca elemental ratios are relatively homogenous for the population sample, with only three outliers demonstrating higher Ba/Ca values (F3-E35, F2-E2 and F3-E65).

Barium occurs in very low concentrations in sea water, therefore the bones of marine fauna can be distinguished from those of terrestrial fauna by examining the barium ratios (Burton and Price 1990; Pate 1994; Wessen et al. 1978). The low Ba/Ca ratios suggest the consumption of marine resources for the population at the Fénix Archaeological

Complex. Moreover, the higher concentrations of Sr/Ca compared to the slightly lower Ba/Ca concentrations also indicate the inclusion of marine resources within the diets of the population (Pearsall 2015:405).

Overall, results for the Sr/Ca and Ba/Ca elemental analyses conducted via LA-ICP-MS and cross referenced with $\delta^{15}N$ isotopic values from this research, indicate that the population sample set were higher-level consumers, likely consuming meat from terrestrial sources. Additionally, Sr/Ca ratios cross-referenced with Ba/Ca ratios indicates a marine contribution into the diets of the population at the Fénix Archaeological Complex. However, Sr/Ca and Ba/Ca values do not show a pattern that correlates with terrestrial/marine resource consumption when compared to nitrogen values. Nevertheless, this may be due to variations in the environmental, physiological and biogeochemical processes, and is hard to establish accurately (see Balter 2004; Burton and Price 1990; Peek and Clementz 2012).

Uranium (U/Ca) Elemental Analyses

In order to better understand the extent of post-burial diagenetic contamination in the skeletal samples from the Fénix Archaeological Complex, concentrations of rare earth elements (REEs) were examined. Elemental uranium (U/Ca) analysis was conducted on the skeletal samples of 37 individuals from the Fénix Archaeological Complex. Uranium was used in the analysis as it begins to be incorporated in human bone after death, meaning that the amount of uranium in the skeletal matrix can give information about the diagenetic processes (see Reynard and Balter 2014). As uranium is not normally found in skeletal tissues, it should be below the detection limit of 0.003 ppm by ICP-MS (Hedges and Millard 1995).

Uranium was plotted against stable oxygen isotope data from the Fénix Archaeological Complex. All of the uranium concentrations for the skeletal samples sit between 0.000000803889 and 0.0000121495 ppm. According to U/Ca research conducted on archaeological skeletal samples (see Knudson et al. 2012b; Price et al. 1992, 2002) these values are very far below the 0.003 detection limit, suggesting that the samples effectively have no uranium. Therefore, we can be confident that there is no post-burial diagenesis
within the skeletal material from the individuals sampled from the Fénix Archaeological Complex.

Radiocarbon Dating

Radiocarbon dating of human skeletal remains from the Fénix Archaeological Complex indicate that the site was occupied between the late Archaic Period through to the end of the Late Intermediate Period (c. 6000–550 BP). Direct dates on skeletal tissues specified dates ranging between 5315 and 557 cal BP, providing further contextual data for the chronology of the population at the Fénix Archaeological Complex.

Past radiocarbon dating of associated shell, obtained dates ranging between 7120 and 2525 cal BP. The new direct dates obtained for individuals from the site allow an expanded chronological resolution at the site and provide a much later timeline for the site, with dates into the Late Intermediate Period (c. 1000–550 BP).

Overall, the combination of direct and associated dates provides a long timeline of over 6000 years for the Fénix population, allowing diet and landscape use to be addressed on geographic, temporal and socio-cultural levels and an improved chronological resolution for the Fénix Archaeological Complex as a whole.

Chapter Overview

Six radiocarbon dates for the Fénix population range between 5315 and 557 cal BP, indicating that the site was occupied from the late Archaic Period to the end of the Late Intermediate Period (c. 6000–550 BP), allowing a more refined chronological resolution for the Fénix Archaeological Complex and a better understanding of diets and mobility patterns through time.

Overall, stable carbon and nitrogen isotope values for the Fénix Archaeological Complex indicate that diets among mid-late Holocene pre-Colombian hunter-gatherers of central Chile consisted predominantly of C_3 foods, with the addition of C_4 cultigens, wild

herbivores and marine foods from lower to middle trophic levels. Due to the sizable sample set, there is a large amount of heterogeneity throughout the population ranging from some individuals eating predominantly C_3 foods and terrestrial herbivores and other individuals eating lower trophic level marine resources with the addition of C_4 based resources.

The Fénix Archaeological Complex results are comparable to individuals from other central Chilean coastal sites, such as Las Brisas 3, Las Brisas 10-14, Concon and Papudo with similar consumption of mixed terrestrial resources and lower trophic level marine resources. However, δ^{15} N values for the Fénix population are higher overall than those of other coastal populations, such as LEP-C, Cancha de Golf 1 and individuals from Las Brisas 10-14, indicating a more regular consumption of terrestrial and marine protein sources. Stable oxygen results contrast to those for other sites in the area, showing a high degree of mobility within the population and the movement between the valleys and the coastal site.

Isotopic results also support some hypotheses about the dietary practices of the Bato cultural complex in central Chile, with results confirming a predominantly C_3 diet, with the addition of terrestrial and marine protein sources from mixed-hunting and gathering practices. However, the addition of C_4 based resources is more common of the Llolleo cultural complex, which is not thought to be present at the Fénix Archaeological Complex (see Galarce and Santander 2011).

Stable oxygen isotopic results for the Fénix Archaeological Complex indicate consumption of coastal to valley waters suggesting that the population were moving between the valleys and coasts during the last 10 years of their lives and reflecting a moderately mobile population excepting a few members who maintained δ^{18} O values close to those for local coastal waters. These results support the hypothesis that the midlate Archaic hunter-gatherers and Bato were both highly mobile cultures. In contrast, the Aconcagua cultural groups likely had seasonal camps between the coast and the interior.

Overall, there are minor differences in the consumption of different food types between males and females within the population. Males, however, have significantly higher $\delta^{15}N$

values than females, indicating higher consumption of marine resources. Additionally, there are no significant differences between the mobility of adult males and females within the population. Similarly, there are no significant differences between resource consumption between adults and sub-adults. Significant differences between the mobility of these two age groups show that adults were likely more mobile than sub-adults.

Stable carbon, nitrogen and oxygen isotope results showed minor variations over time, with mid-late Archaic populations consuming a higher amount of marine resources and individuals from later populations regularly consuming wild herbivores. A mixture of C₃ and C₄ based resources is seen throughout the temporal/cultural periods at the Fénix Archaeological Complex; however, it is likely that the population was consuming more C₄ based resources in later time/cultural periods.

Additionally, strontium and barium elemental ratios show that the population were likely eating foods from higher trophic levels with the additional consumption of marine resources. Moreover, U/Ca values are low, suggesting minimal post-diagenetic contamination within the sample set.

Using archaeological, palaeopathological and isotopic data from the skeletal and mortuary evidence belonging to the Fénix Archaeological Complex, a comparison of currently held archaeological theories regarding marine versus terrestrial resource use and the adoption of agriculture/retention of hunter-gatherer economies have been made. Additionally, the results from this analysis have been compared to other international and regional studies regarding human resource and landscape use and adaptive strategies in the mid-late Holocene.

A further examination of the diet and landscape use of the population has been conducted using stable carbon, nitrogen and oxygen isotope analyses, adding additional information to the bioanthropological reports. As such, this research project has contributed considerable new data about the collection, thereby allowing a much-expanded position from which to make inferences about the past lifeways of the population at the Fénix Archaeological Complex.

CHAPTER SEVEN: CONCLUSIONS

Overview

The overall aim of this research project was to examine the diet and landscape use of mid-Archaic to Late Intermediate Period (c. 7000–550 BP) central Chilean populations from the Fénix Archaeological Complex. Stable carbon, nitrogen and oxygen isotope analyses of 73 human skeletal samples were used to assess changes and/or continuities in the diet and mobility of the Fénix populations, including, but not limited to, marine versus terrestrial resource use, the adoption of agricultural practices and population movement across the landscape.

Additionally, elemental concentrations were examined in order to add further dietary information and answer questions about post-burial diagenesis within the sample set. Furthermore, six radiocarbon dates were obtained in order to provide an improved chronological resolution for the site, allowing the diets of individuals and their landscape use of the site to be explored within a more accurate timeframe.

This chapter outlines the key findings from this research project, overviews the results placing them in a global and regional research context and finishes with some final reflections about the project, followed by recommendations for future research in the area.

Key Findings

This research presents the largest single site sample set that has been undertaken for isotopic research in central Chile to date. As such, these results allow an in-depth study of a coastal central Chilean site throughout the mid-late Holocene. This section provides a summary of the results and research undertaken in this thesis and the key findings for this project.

An outline of key findings for this project are as follows:

- Stable carbon and nitrogen isotope analysis demonstrate that the populations at the Fénix Archaeological Complex were consuming marine resources from lower trophic levels from the mid-late Archaic Period through to the Late Intermediate Period (c. 7000–550 BP). Heterogeneity within the population indicates that some individuals during the Early Ceramic Period were not consuming marine resources, but instead were eating terrestrial fauna, such as wild herbivores. Additionally, the wide range of values found in the population also reveals that some members of the population were eating marine resources from mid to high trophic levels, such as large fish and marine mammals.
- 2. Stable carbon and nitrogen dietary values from the population at the Fénix Archaeological Complex do not adequately inform us about the adoption of agricultural practices at the site. While many members of the population were consuming C₄ (maize-based) resources, as part of a mixed diet, only three individuals in the total sample (all from the Fénix 3 site) have carbon and nitrogen isotopic values indicating a significant consumption of maize. Thus, stable carbon isotope values do not indicate the adoption of maize-based agricultural practices during any time periods at the Fénix Archaeological Complex. Instead, it is likely that the consumption of maize was supplementary to a diet including C₃ resources, wild herbivores and marine resources from lower trophic levels.
- 3. Variances in the consumption of different food types between ages and sexes within the population are minimal, with values being very close to each other for all groups. However, males show a significantly (according to unpaired t-testing) higher consumption of δ^{15} N-enriched foods, potentially due to a higher consumption of marine resources or physiological differences. Additionally, adults were significantly (according to unpaired t-testing) more mobile than subadults within the population suggesting that they travelled more outside of their local area. These differences cannot be contributed to the class/status of particular members of the population as mortuary contexts were not recorded for

many individuals upon excavation and therefore class/status cannot be linked to isotopic values.

- 4. Stable oxygen isotope results reflect heterogenous water consumption throughout the population with values ranging from those for the consumption of inland valley waters to those closer to coastal water consumption. These results indicate that it is likely that the population were moving between the valleys and coasts during the last ten years of their lives and then either died on the coast or were taken back to the coast for burial at the Fénix Archaeological Complex.
- 5. Oxygen isotope analysis reflects a highly mobile population with all members of the population showing δ^{18} O values for at least some movement out of the local coastal area. While some δ^{18} O values approached those for coastal meteoric water consumption, most were indicative of the consumption of waters further inland than their burial site at the Fénix Archaeological Complex.
- 6. The presence of foreigners in the burial population could not be determined due to the high mobility of the population. No members of the population demonstrated δ^{18} O values that were a match with those of local meteoric waters, therefore it is likely that either the individuals from the Fénix Archaeological Complex were all foreigners to the burial population or were moving between the valleys and the coasts.
- 7. The main issue impinging on the isotopic interpretation of the skeletal samples from the Fénix Archaeological Collection was estimating the percentage of maize in a mixed C₃-C₄ diet and the associated problems that come with dietary estimations. This issue has been discussed in-depth in past research (see Tykot et al. 2009) and was moderated in this project by giving approximations (e.g., low, moderate, high) of the amount of maize in the diet, with the raw δ^{13} C results included in the thesis for future researchers to examine and redefine if need be (Appendix D).
- 8. Trace element analysis of Ba/Ca and Sr/Ca ratios can identify trophic level and marine versus terrestrial resource consumption through an examination of the

process of biopurification and environmental data. Results for the Sr/Ca and Ba/Ca ratios from the Fénix Archaeological Complex suggested that the population at the site were consuming high trophic level foods including marine resources. However, Sr/Ba ratios do not show any particular patterns correlating with the δ^{15} N data, highlighting the need for future research on this topic.

- 9. The analysis of uranium trace element ratios by LA-ICP-MS addressed problems with post-burial diagenesis in the sample set by a demonstration of the amount of uranium that has been absorbed into the bone. All uranium levels in the skeletal material were far below the ICP-MS detection limit of 0.003ppm and therefore indicate that there is no post-burial uranium uptake in the bone samples from the Fénix Archaeological Complex.
- 10. Radiocarbon dating expanded the timeline for the Fénix Archaeological Complex, allowing for better chronological resolution at the site. Six radiocarbon dates from four different areas within the site allowed for a comprehensive refinement of the chronology of the site and clarification of relative dates in stratigraphically complex areas.

The key findings in this thesis answer the research questions stated in the introduction chapter and expand the data set for coastal central Chilean sites. These results demonstrate the continued consumption of C_3 -based food resources over time, with the addition of C_4 -based foods supplemented with marine foods from lower trophic levels. This thesis contributed to the growing number of isotopic studies in central Chile which have demonstrated the use of both archaeological and chemical analyses to form a more holistic picture of past lifeways. Further research into mid-late Archaic populations and isotopic baseline values for C_4 resources in central Chile will aid in resolving the complexities that surround the relative contributions of maize into the diets of central Chileans. Additionally, further isotopic studies on larger single site sample sets will allow a better comparison of the Fénix Archaeological Complex to other sites in the area.

Global and Regional Research Context

This research project has used isotopic data from the population at the Fénix Archaeological Complex to contribute to theories on human diet and landscape use, placing the site into both a global and regional context. Globally, stable carbon, nitrogen and oxygen isotope analyses have focused on issues such as the use of marine versus terrestrial resource use (see Dillehay 2008; Gaspar et al. 2008; Giorgi et al. 2005; Le Bras-Goude et al. 2006; Price et al. 2007; Richards et al. 2003; Schulting 2005), the adoption of agricultural practices (see Falabella et al. 2007; Falabella et al. 2008; Hedges and Reynard 2007; Koch 2007; Sanhueza and Falabella 2010), and the mobility of populations across landscapes (see Beard and Johnson 2000; Budd et al. 2001, 2003; Gil et al. 2011; Hodell et al. 2004; Knudson 2009; Knudson et al. 2012b; Müller et al. 2003; Pate 1995, 2000; Pate et al. 2002; Price et al. 2000; Ugan et al. 2012).

Marine resource use has been varied across the world and over time, with archaeological and isotopic evidence indicating that some populations heavily exploited marine food resources throughout time (see Dillehay 2008; Gaspar et al. 2008; Giorgi et al. 2005; Le Bras-Goude et al. 2006; Price et al. 2007; Richards et al. 2003; Schulting 2005), while others demonstrated intermittent or partial marine food resource utilisation mixed with terrestrial or lacustrine consumption (see Richards et al. 2003; Schulting 2005), and others revealed minimal to no marine resource consumption over time despite living in coastal environments (see Badré and Le Mort 1998; Jones 1971; Papathanasiou 2003). Stable carbon and nitrogen isotope analysis at the Fénix Archaeological Complex has revealed the varied consumption of marine foods over time from predominantly lower trophic levels. This is similar to other sites around the world that demonstrate partial or intermittent marine food utilisation mixed with other food resources.

At a regional level, the Fénix Archaeological Complex population demonstrated similar stable carbon and nitrogen isotope values when compared with other central Chilean coastal populations (such as Las Brisas 3, LEP-C, Cancha de Golf 1 and Papudo) but revealed higher δ^{15} N values compared to the coastal site of Las Brisas 10-14 and many inland central Chilean sites, such as Valle Verde and Pocochay (see Falabella et al. 2007; Sanhueza and Falabella 2010; Swift et al. 2017). However, these differences may be due to the differences in population numbers and the range of values within the Fénix

population, as the other sites have between two and ten skeletal samples from the one location whereas the site of Fénix has 73 skeletal samples from one location, allowing a much greater spread of results. This research fits within the central Chilean narrative because it demonstrates local variation in values that correlate with the archaeological data in the region, highlighting similarities and differences between food resource use.

The use of terrestrial-based dietary resources has been examined throughout the world, over time, starting with hunter-gatherer populations and continuing through to more sedentary populations practicing various forms of agriculture (see Pearsall 2008; Pinhasi and Stock 2011; Santoro et al. 2011b). The adoption of agricultural practices around the world started around the same time but for various reasons. While many populations chose to adopt agricultural practices, some populations, such as Aboriginal Australians, the !Kung San of Africa, and the coastal hunter-gatherers of California and northwest North America, provide examples of cultures who did not choose to participate in agricultural practices (see Gilligan 2010; Lee 1979; Lee and Devore 1968; Price and Brown 1985). In contrast, agricultural practices in South America developed during the early-mid Holocene across the continent but varied significantly from one region to the next (see Pearsall 1992; Pearsall 2008; Perez et al. 2017).

In central Chile archaeological evidence of agricultural practices was found during the late Archaic Period (c. 3000 BP) in the form of quinoa horticulture (see Planella et al. 2005). Following this, the Early Ceramic Period saw an increase in food production, with archaeological evidence for agricultural practices at sites such as Lenka Franulic and El Mercurio (see Falabella et al. 2007; Falabella et al. 2008; Planella et al. 2005; Sanhueza and Falabella 2010). However, while many central Chilean populations demonstrated stable carbon isotopic evidence for the consumption of C₄ food resources, many populations, such as Maria Pinto, LEP-C and Las Brisas participated in a mixed resource-based economy where hunting and gathering practices are supplemented by cultigens (see Falabella et al. 2007; Falabella et al. 2008; Sanhueza and Falabella 2010). Stable carbon and nitrogen isotope results from the Fénix Archaeological Complex correlate with other central Chilean populations participating in hunting and gathering practices with the addition of C₄ cultigens, thus expanding the data set for mid-Archaic to Late Intermediate Period populations in central Chile.

Stable oxygen isotope values have been used to examine the mobility of prehistoric humans around the world. Globally, stable oxygen isotope analysis has contributed information about the identification of foreigners in burial populations (see Knudson et al. 2012a, Knudson et al. 2012b) and human mobility throughout the lifetime through an analysis of teeth and bones (see Budd et al. 2004; Knudson et al. 2012b; Kohn et al 2003; Müller et al. 2003; Rubenstein and Hobson 2004; Turner et al. 2009).

Locally, stable oxygen isotope analyses from the Fénix Archaeological Complex contrast with δ^{18} O values found from other nearby coastal populations. The sites of LEP-C and Cancha de Golf 1 demonstrated a general lack of inland mobility, with δ^{18} O values coinciding with local waters (see Falabella et al. 2007; Sanhueza and Falabella 2010). Conversely, the Fénix Archaeological Complex population is similar to other populations in the area, such as Las Brisas 10-14, which demonstrated δ^{18} O values coinciding with intermittent water consumption between the inland valleys and the coasts.

Final Reflections

This research has contributed to an understanding of mid-late Holocene resource and landscape use in central Chile through isotope and elemental analyses of human bone collagen and apatite via the use of the Fénix Archaeological Complex as a case study. The results of this thesis highlight the value of chemical analyses to archaeological research and how they can contribute archaeological theories about diet and landscape use.

This research contributes to information about the application of isotope analysis, archaeological analysis, palaeobotanical analysis, elemental analysis and radiocarbon dating to obtain a more holistic picture of this coastal central Chilean population. This research also aids in assessing the independent contribution that isotopic and elemental studies can generate in comparison to archaeological data, which has a higher potential of over or under representing the amounts and kinds of foods that populations were consuming.

Stable carbon and nitrogen isotope analyses provided information about the dietary composition of past human populations (marine versus terrestrial foods and wild foods versus cultivated foods) through an examination of bone collagen and apatite from prehistoric skeletons. Stable oxygen isotope analysis allowed insights into the movement of individuals around the landscape and provided information on whether members of the population at the Fénix Archaeological Complex were previously from the coast, valleys or highlands.

Oxygen isotopes also provided the potential to test inferences made as a result of stable carbon and nitrogen studies by comparing carbon and nitrogen isotopic outliers with oxygen isotopic results (see Knudson et al. 2009, 2012b; Sanhueza and Falabella 2010; White et al. 1998). Results on the diet and mobility of the population illustrated how the multiple isotope and elemental studies conducted on the Fénix Osteological Collection not only supplemented each other, but also complemented the standard archaeological data from the sites, adding a quantitative element of information about changes and/or continuities in the diet and mobility of the populations. Additional radiocarbon dating of the site via the skeletal remains also contributed to a comparison with the relative dating conducted at the site through ceramic typologies, thereby further clarifying the chronological resolution of the Fénix Archaeological Complex.

Furthermore, this thesis contributes to the growing research focus in central Chilean archaeology concerning the use of marine dietary resources and the adoption of agriculture through the consumption of maize-based resources (see Falabella et al. 2008; Falabella et al. 2008; Planella and Tagle 2004; Planella et al. 2011; Sanhueza and Falabella 2010). The research is relevant to an understanding of the characteristics of the human occupation of the Fénix Archaeological Complex, since it is a site with a complex formational history with significant contextual associations as evidenced by the presence of domestic and funerary features throughout the site.

Moreover, it is relevant to note that this project fulfils one of the recommendations in the Análisis de Restos Bioantropológicos: Fénix 3 (Bioanthropological remains analysis: Fénix 3) report (see Rebolledo 2012a:81). This is the recommendation that isotopic studies be conducted on the skeletal material at the site. Thus, it also contributes to the satisfying the requirements of the Chilean National Council for Cultural Heritage (*Consejo de Monumentos Nacionales*), on archaeological sites in Chile, which have been subject to salvage due to construction.

To conclude, stable carbon, nitrogen and oxygen isotope analyses of human skeletal material at the Fénix Archaeological Complex tells the story of a complex population who were consuming mixed food resources (C_3 - and C_4 -based) with the addition of wild herbivores and marine resources from lower trophic levels, while travelling between the valleys and the coast during the mid-late Holocene.

Future Research: Recommendations

As discussed throughout this thesis, prior isotopic studies in central Chile have been focussed on the diet and landscape use of multiple populations through small numbers of samples from across the landscape (e.g., coasts, valleys and highlands). As such, recommendations for future research principally involve the sampling and analysis of greater numbers of human skeletal remains from single site populations in central Chile. Additionally, the following list briefly outlines recommendations for future research in the area:

- 1. Additional radiocarbon dating of Archaic Period skeletal samples in order to further refine the chronology for early central Chilean populations.
- 2. More stable carbon, nitrogen and oxygen isotope analyses conducted on larger single site sample sets in order to confirm or refine patterns found in this research and establish site trends, forming a fuller picture of the lifeways of past central Chilean populations.
- Further studies into C₄-based resource use in central Chile with more baseline C₄ samples analysed and cross referenced with archaeological and palaeobotanical data.
- 4. Publication of more combined chemical and archaeological studies in central Chile in order to allow for greater reference material for central Chilean studies.
- 5. Further research into carbon apatite to diet spacing for the clarification of maize in past diets.
- 6. More research into stable carbon collagen to apatite spacing in order to clarify dietary incorporations.

These recommendations are by no means a criticism of the excellent work that has already been done in the region, or on the analytical methods, but are simply gaps that were identified for further investigation while undertaking the chemical and archaeological research of the population at the Fénix Archaeological Complex in central Chile.

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APPENDICES

Appendix A

Ethics email from Flinders University ethics manager

From: Peter Wigley <peter.wigley@flinders.edu.au> Subject: RE: Ethics question Date: 20 September 2013 9:15:12 am ACST To: Bianca Petruzzelli
 biancapetruzzelli@gmail.com>

Hi Bianca,

Thanks for your enquiry. I don't believe that you require ethics approval from Flinders for this project.

All the best for your research.

Kind regards, Peter

Dr Peter Wigley Manager, Research Ethics & Integrity Research Services Office Flinders University | GPO Box 2100 | Adelaide SA 5001 | Australia P: +61 8 8201 5466 | M: +61 (0)413 183 761 | F: +61 8 8201 2035 | E: peter.wigley@flinders.edu.au www.flinders.edu.au/research Permit from the National Council for Cultural Heritage (Consejo de Monumentos Nacionales) in Chile.



 ORD. N°:
 001447/15

 ANT.:
 Carta del 27.04.2015 (Ingreso CMN N° 2436 del 27.04.2015).

 MAT.:
 Autoriza el envío de 73 muestras arqueológicas a Australia, para análisis en el marco de la investigación "Proposed skeletal research for the Fenix osteological collection, Quintero Bay, Chile" para la realización de análisis de isótopos estables y de C₁₄ AMS.

Santiago, 2 9 MAYO 2015

- A: SR. PATRICIO GALARCE CORNEJOS ARQUEÓLOGO ARCHEOS CHILE
- DE: SRA. SUSANA SIMONETTI DE GROOTE SECRETARIA EJECUTIVA (S) CONSEJO DE MONUMENTOS NACIONALES

A través del presente y junto con saludarle muy cordialmente, este Consejo acusa recibo de la carta citada en el antecedente, mediante la cual solicita autorizar el traslado de 73 muestras arqueológicas a Australia.

Lo anterior, para realizarles análisis en los siguientes laboratorios: Flinders University of South Australia Senior Chemistry Laboratory, Adelaide, South Australia; Commonwealth Scientific Industrial Research Organisation (CSIRO) (análisis de isótopos) y Australian Nuclear Science and Technology Organisation (ANSTO) (datación por radiocarbono (AMS)).

Estos análisis se realizarán en el marco de la investigación "Proposed Skeletal Research for the Fenix Osteological Collection, Quintero Bay", cuya investigadora es la



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Srta. Bianca Petruzzelli. Estas muestras provienen de 4 sitios arqueológicos, Fénix 2, Fénix 3, Fénix 8 y Fénix 12, asentamientos de grupos costeros prehispánicas de Chile Central.

Las muestras serán sometidas a análisis de isótopos estables y de C_{14r} los cuales serán completamente destructivos. El objetivo de este análisis es la obtención de indicadores dietarios y de movilidad de las poblaciones costeras de Chile Central.

Los materiales incluidos en esta muestra serán trasladados para fines científicos, en el marco del mencionado proyecto. Dichas muestras corresponden a las detalladas en el inventario adjunto.

Estas muestras serán transportadas vía aérea y deberán ser trasladadas considerando criterios de conservación e identificación que aseguren su integridad.

Este Consejo autoriza el traslado de las muestras a Australia para realización de estos análisis que serán destructivos. Solicitamos que una vez finalizados los análisis, se remita un informe ejecutivo que dé cuenta de su realización efectiva y de sus resultados. En el caso que algunas de estas muestras en definitiva no sean sometidas a análisis destructivo, deberán retornar al país.

Deseándole éxito en su investigación, se despide cordialmente de usted,



- Archivo Consejo Monumentos Nacionales. M\$V/JJA/msma



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ANEXO:	ANEXO: INVENTARIO DE MUESTRAS						
N°	Sitio	Bloque	Unidad	Сара	Nivel	Individuo	Porción anatómica
1	Fénix-3	Bloque N°1	1-2	4		E1	Falange
2	Fénix-3	Bloque N°1	2-3	5		E2	Falange
3	Fénix-3	Bloque N°14	1-4	3-4	A-A	E3	Falange
4	Fénix-3	Bloque N°7	4	3	в	E4	Falange
5	Fénix-3	Bloque N°17	1	1	с	E5	Falange
6	Fénix-3	Bloque N°17	4	1	в	E6	Falange
7	Fénix-3	Bloque N°22	2	2	с	E7	-
8	Fénix-3	Bloque N°25	1-2	3	A	E9	Falange
9	Fénix-3	Bloque N°20	4	2	в	E10	Falange
10	Fénix-3	Bloque N°26	3	3	в	E12	Falange
11	Fénix-3	Bloque N°26	2	3	A	E13	Falange
12	Fénix-3	Bloque N°67	1	1	D	E14	Falange
13	Fénix-3	Bloque N°41	3	2	А	E15	Falange
14	Fénix-3	Bloque N°17	3	2	A	E16	Falange
15	Fénix-3	Bloque N°38	2	2	в	E17	Falange
16	Fénix-3	Bloque N°40	4	1	F	E18	Falange
17	Fénix-3	Bloque Nº42	1	2	A	E19	-
18	Fénix-3	Bloque Nº42	2	3	A	E20	Falange
19	Fénix-3	Bioque Nº40	3	1	F	E21	Falange
20	Fénix-3	Bloque N°38	1-2-3-4	3	в	E22	Falange
21	Fénix-3	Bloque N°39	3-5	2	в	E23	Falange

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22	Fénix-3	Bloque N°21	3-4	3	E	E24	Falange
23	Fénix-3	Bloque N°8	3	3	В	E25	Falange
24	Fénix-3	Bloque N°54	3	2	в	E26	Falange
25	Fénix-3	Bloque N°53	1	1-B	в	E27	Falange
26	Fénix-3	Bioque N°53	2-7	1	с	E28	Falange
27	Fénix-3	Bloque N°53	1	1	D	E29	Falange
28	Fénix-3	Bloque N°57	1	1	с	E30	Falange
29	Fénix-3	Bloque N°53	8-10	1	в	E31	Falange
30	Fénix-3	Bloque N°57	5-6-7	1	с	E32	Falange
31	Fénix-3	Bloque N°57	5-6	1	D	E33	Falange
32	Fénix-3	Bloque N°53- 67	5-7	1	с	E34	Falange
33	Fénix-3	Bloque N°58	3-6	1	E	E35 Falange	
34	Fénix-3	Bloque N°53	2	2	А	E36	-
35	Fénix-3	Bloque N°55	1	3	в	E37	-
36	Fénix-3	Bloque N°57	4	1	с	E38	Falange
37	Fénix-3	Bloque N°53	2-17-8	2	в	E39	Falange
38	Fénix-3	Bloque N°58	2-8	1	E	E40	Falange
39	Fénix-3	Bloque N°62	3-4-5-6	2	в	E41	Falange
40	Fénix-3	Bloque N°58	4	3	A	E42	Falange
41	Fénix-3	Bloque N°59	1-5	2	с	E43	
42	Fénix-3	Bloque N°69	1	1	в	E44	Falange
43	Fénix-3	Bloque N°68	1-2-3-4	3	А	E45	Falange
44	Fénix-3	Bloque Nº68	1	1	G	E46	Falange
45	Fénix-3	Bloque N°69-	1	1	E	E47	Falange

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	46	Fénix-3	Bloque N°57	5-6	1	E	E48	Falange
	47	Fénix-3	Bloque N°	A69		-	E49	Falange
	48	Fénix-3	Bloque N°	A63/A23	2	в	E50	Falange
	49	Fénix-3	Bloque N°	A55	2	А	E51	Falange
	50	Fénix-3	Bloque N°68	4	3	A	E53	Falange
	51	Fénix-3		A24-A87	2B-2B		E55	Falange
	52	Fénix-3		A86/A13			E56	Falange
	53	Fénix-3		A/3/AMPLIACIÓN AB6	2	В	E57	-
	54	Fénix-3		32	1	с	E58	-
	55	Fénix-3		A28	2	А	E59	Falange
	56	Fénix-3		A42	3	D	E60	Falange
	57	Fénix-3		A71-A66			E61	Falange
	58	Fénix-3		A44-A64	3C-3A		E63	Falange
	59	Fénix-3		A62			E64	-
	60	Fénix-3		A79/A70			E65	Falange
	61	Fénix-3		A48	2	А	E66	Falange
	62	Fénix-3		A43-A43 AMPLIACIÓN	1E-1C		E67	Falange
	63	Fénix-3		A69			E68	Falange
	· 64	Fénix-3		A86	2	D	E69	Falange
	65	Fénix-2		1 (EXT. POZO 10)			E1	Falange
	66	Fénix-2		1 (EXT. POZO 10)			E2	Falange
	67	Fénix-8		1	2	E	E1	Falange
	68	Fénix-8		1	1/RASGO 1	с	E2	Falange

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69	Fénix-8	4	2	с	E3	Falange
70	Fénix-8	16	1	в	E4	Falange
71	Fénix-8	24 Y 27	1	в	E5	Falange
72	Fénix-8	27	1	в	E6	Falange
73	Fénix-12	1	1	5	E1	Falange



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Email from the Department of Agriculture about importing the Fénix skeletal samples.

From: "Hogan, Stuart" <Stuart.Hogan@agriculture.gov.au> Subject: RE: Quarantine Entry for Human Skeletal Samples - A message from the Department of Agriculture website [SEC=UNCLASSIFIED] Date: 8 August 2014 12:56:34 pm ACST To: Bianca Petruzzelli

diancapetruzzelli@gmail.com>

Hi Bianca,

Provided they are 100% clean and uncontaminated, the bones represent no biosecurity risk and can be simply released without any treatment.

Gamma irradiation would only be necessary if the archaeological samples were contaminated with soil etc.

Kind regards,

Stuart.

Appendix B

Raw data for marine percentage calculations

В	С	D	Е	F	G H		1	к	L	м	N	0	Р	Q	R	S
	All Terrestri	al		All Marine	ine Adding appropriate percentage		rcentages to	ogether								
	-20.10			-8.70		Mixed men	u									
100%	-20.10		0%	0.00	100T, 0	-20.10			Percentage of Marine food in mixed diet							
90%	-18.09		10%	-0.87	90T, 10	-18.96									120%	
80%	-16.08		20%	-1.74	80T, 20	-17.82									4.0001	
70%	-14.07		30%	-2.61	70T, 30	M -16.68			00				100%			
60%	-12.06		40%	-3.48	60T, 40	-15.54			e	y = 0.08772x	+ 1.76316				80%	_
50%	-10.05		50%	-4.35	50T, 50	-14.40			Jari				- C			
40%	-8.04		60%	-5.22	40T, 60	-13.26			8	T age T				60%		
30%	-6.03		70%	-6.09	30T, 70	-12.12			nta		1			40%		
20%	-4.02		80%	-6.96	20T, 80	-10.98			er ce							
10%	-2.01		90%	-7.83	10T, 90	-9.84			~						20%	
0%	0.00		100%	-8.70	OT, 100	-8.70									0%	
									-25.00	-20.0	D	-15.00	-10.00	-5.00	(0.00
												carbon in s	sample			
Liss equation from	m chart to clu	o the nercen	t	ring food (c) fr	som the corbon in	the comple (v)										
Use equation from	CO16	le the percen	lageonna	anne ioou (y) ii	rom the carbon m	the sample (x)										
y-0.08//2x+1./0	by chart on	untion		h	wompirical caust	ion.										
Your complex	porcontago	maringfood		0	(=(dC12.Tm)/(Mm	Tm)										
-19 2	16 67%	inarine loou		· · · · · ·	16 67%	-1111)										
-16.4	32.46%				32.46%											
-13.4	58 77%				58 77%											
-17.5	22.81%				22.81%											
-13.2	60.53%				60.53%					-						
-18	18.42%				18.42%											

Appendix C

Stratigraphic table and profiles for the excavated areas at Fénix 3 (courtesy of Galarce and Santander 2011)

Table C.1 Table illustrating the stratigraphic and temporal correlation between the units and sectors evaluated at Fénix 3. Table courtesy of Galarce and Santander (2011:36).

Sector W]		Sector S		Sector N	7	Sector Central	Sector Marginal
Bloque 6	A45	Bloque 1 - 11	A58	A66-A71	A62	A13-A86	Bloque 53	A82-A89
Capa 1	Capa 1	Capa 1	Capa 1	Capa 1	Capa 1	Capa 1	Capa 1	Capa 1
Capa 2	Capa 2	Capa 2	Capa 2	Capa 2	Capa 2	Capa 2	Capa 2	Capa 2
Capa 3	Capa 3	Capa 3	Capa 3	Capa 3				
Capa 4	Capa 4		Capa 4	Capa 4				
Capa 5	Capa 5				_			
Capa 6								

Paleoduna Pleistoceno - Holoceno
Ocupación Arcaico Medio - Tardío
Paleoduna Holoceno
Ocupación Arcaico Medio - Tardío
Ocupación Alfarero Temprano
Ocupación Alfarero Temprano

The below images are from a report on the sites of Fénix 3 and Fénix 8 by Galarce and Santander (2011)



Figure C.1 Stratigraphic profile (N) of Block 11, Units 1 and 2. The lines mark the significant layers segmented post excavation within Stratum 1.



Figure C.2 Stratigraphic Profile (E) of Block 11, Unit 2 and Block 1, Unit 2. Segmented lines mark the significant post excavation layers within Stratum 1.


Figure C.3 Stratigraphic profile of Block 6. Segmented lines mark the significant post excavation layers within Layer 1. The black arrows indicate the points where samples for 14C dating were obtained.



Figure C4 Stratigraphic profile (W) of the A45 unit. Layer 3 indicates the presence of a lens of ash from a fire. The white arrows indicate human remains for the individual 49.



Figure C.5 Stratigraphic profile (W) of the A62 unit. The pocket in Layer 1 corresponds to the funerary context of individual 64 (indicated by the white arrow).



Figure C.6 Profile of A13 (left) and A86 units (right), where pockets intruding from Layer 1 and Layer 2 are shown and associated with the appearance of funerary contexts—individuals 57 and 68 (shown with black arrows).



Figure C.7 Stratigraphic profile (N) of Block 53. Shells and fragmented lenses associated with funerary contexts recorded in Layer 1 are shown.



Figure C.8 Stratigraphic profile (N) of Unit A58 showing the stratigraphic sequence.



Figure C.9 Stratigraphic profile (N) of the A66 and A71 units. The arrow indicates where individual 61 was deposited.



Figure C.10 Profile (E) stratigraphic units of A82 and A89.

Stratigraphic profiles for the excavated area at Fénix 8 (courtesy of Galarce and Santander 2011)



Figure C.11 Profile of stratigraphic unit 18 (N), Fénix 8.

	Α	В	с	D	E	F	G	н		J	к	L	М
1	run	Name	d15N	err	%N	err	d13C	err	%С	err	C:N(a)	Average N	Averaage C
2	1	F12-E01	11.4	0.1	14.9	0.2	-17.8	0.04	41.8	1.3	3.3		
3	2	F2-E01	10.0	0.2	17.1	0.7	-18.8	0.07	45.5	2.7	3.1	10.1	-18.8
4	2	F2-E01	10.2	0.2	16.7	0.7	-18.7	0.07	44.8	2.7	3.1		
5	2	F2-E02	8.9	0.2	15.8	0.6	-17.4	0.07	43.0	2.6	3.2		
6	2	F3-E01	10.8	0.2	17.3	0.7	-19.3	0.07	44.8	2.7	3.0	10.7	-19.3
7	2	F3-E01	10.6	0.2	17.1	0.7	-19.3	0.07	47.4	2.8	3.2		
8	1	F3-E02	12.6	0.1	15.3	0.2	-17.3	0.04	42.3	1.3	3.2		
9	1	F3-E03	13.7	0.1	14.3	0.2	-16.1	0.04	39.0	1.2	3.2		
10	1	F3-E04	12.3	0.1	14.0	0.2	-17.6	0.04	38.8	1.2	3.2		
11	2	F3-E05	11.5	0.2	17.3	0.7	-15.5	0.07	45.9	2.8	3.1	11.5	-15.4
12	1	F3-E05	11.5	0.1	15.2	0.2	-15.2	0.04	43.1	1.3	3.3		
13	2	F3-E06	10.8	0.2	16.0	0.6	-18.8	0.07	44.5	2.7	3.3	10.8	-18.7
14	1	F3-E06	10.8	0.1	12.7	0.1	-18.6	0.04	35.1	1.1	3.2		
15	2	F3-E07	7.0	0.2	17.1	0.7	-20.4	0.07	44.2	2.7	3.0		
16	2	F3-E09	14.2	0.2	14.1	0.6	-15.9	0.07	39.9	2.4	3.3	14.3	-15.7
17	1	F3-E09	14.3	0.1	13.8	0.2	-15.5	0.04	38.3	1.1	3.2		
18	2	F3-E10	14.2	0.2	18.7	0.7	-15.9	0.07	48.4	2.9	3.0		
19	1	F3-E12	10.9	0.1	14.7	0.2	-15.8	0.04	41.7	1.3	3.3		
20	2	F3-E13	11.9	0.2	15.9	0.6	-17.5	0.07	42.1	2.5	3.1		
21	2	F3-E14	7.7	0.2	15.7	0.6	-20.1	0.07	42.0	2.5	3.1		
22	2	F3-E15	12.4	0.2	16.7	0.7	-16.7	0.07	44.2	2.7	3.1		
23	2	F3-E16	12.9	0.2	16.5	0.6	-17.4	0.07	45.6	2.7	3.2	13.0	-17.3
24	1	F3-E16	13.0	0.1	15.4	0.2	-17.2	0.04	43.0	1.3	3.3		
25	2	F3-E17	7.9	0.2	17.3	0.7	-13.9	0.07	44.7	2.7	3.0	8.0	-14.0
26	2	F3-E17	8.1	0.2	16.2	0.6	-14.0	0.07	45.3	2.7	3.3		
27	2	F3-E18	13.7	0.2	17.4	0.7	-13.7	0.07	45.8	2.7	3.1	13.9	-13.6
28	1	F3-E18	14.1	0.1	15.3	0.2	-13.4	0.04	42.3	1.3	3.2		
29	1	F3-E20	9.9	0.1	16.6	0.2	-16.8	0.04	46.5	1.4	3.3		
30	2	F3-E21	12.4	0.2	18.2	0.7	-17.2	0.07	47.4	2.8	3.0		
31	2	F3-E21										double drop	
32	2	F3-E22	13.3	0.2	15.8	0.6	-15.5	0.07	44.1	2.6	3.3	13.3	-15.4
33	1	F3-E22	13.3	0.1	14.4	0.2	-15.3	0.04	38.5	1.2	3.1		
34	2	F3-E23	12.9	0.2	15.7	0.6	-17.7	0.07	41.7	2.5	3.1		
35	2	F3-E24	13.3	0.2	14.0	0.5	-15.4	0.07	38.7	2.3	3.2		
36	2	F3-E25	13.6	0.2	18.6	0.7	-16.2	0.07	48.6	2.9	3.1		
37	2	F3-E26	7.7	0.2	15.7	0.6	-18.0	0.07	41.1	2.5	3.1		
38	2	F3-E27	11.1	0.2	16.3	0.6	-18.7	0.07	43.0	2.6	3.1		
39	2	F3-E28	11.4	0.2	15.4	0.6	-18.8	0.07	43.1	2.6	3.3	11.4	-18.7
40	1	F3-E28	11.4	0.1	15.3	0.2	-18.6	0.04	43.1	1.3	3.3		
41	1	F3-E29	12.0	0.1	15.2	0.2	-17.8	0.04	41.0	1.2	3.1		
42	1	F3-E31	11.5	0.1	14.0	0.2	-17.9	0.04	38.3	1.1	3.2		
43	1	F3-E32	12.7	0.1	14.7	0.2	-17.2	0.04	41.4	1.2	3.3		
44	2	F3-E33	12.8	0.2	14.5	0.6	-17.5	0.07	40.9	2.5	3.3		
45	1	F3-E34	12.9	0.1	15.9	0.2	-16.8	0.04	44.7	1.3	3.3		
46	2	F3-E35	14.2	0.2	8.2	0.3	-14.2	0.07	24.1	1.4	3.4	probably weighi	ng issue
47	2	F3-E35										double drop	
48	2	F3-E36										double drop	
49	1	F3-E37	13.4	0.1	14.7	0.2	-16.6	0.04	42.1	1.3	3.3		
50	2	F3-E38	12.5	0.2	19.1	0.7	-13.5	0.07	49.4	3.0	3.0		
51	2	F3-E39	10.2	0.2	13.4	0.5	-19.5	0.07	37.6	2.3	3.3	10.4	-19.4
52	1	F3-E39	10.5	0.1	13.0	0.1	-19.3	0.04	36.6	1.1	3.3		
53	1	F3-E40	13.6	0.1	15.7	0.2	-16.3	0.04	45.1	1.4	3.4		
54	2	F3-E41	15.1	0.2	17.9	0.7	-14.8	0.07	47.1	2.8	3.1	15.2	-14.6
55	1	F3-E41	15.2	0.1	16.3	0.2	-14.4	0.04	46.2	1.4	3.3		
56	2	F3-E42	13.9	0.2	15.1	0.6	-16.6	0.07	43.3	2.6	3.3	13.9	-16.5
57	1	F3-E42	13.9	0.1	14.6	0.2	-16.3	0.04	40.6	1.2	3.3		
58	2	F3-E43	8.8	0.2	16.8	0.7	-18.9	0.07	43.6	2.6	3.0		
59	2	F3-E44	11.4	0.2	13.7	0.5	-18.3	0.07	38.4	2.3	3.3	11.4	-18.3
60	2	F3-F44										double drop	

Raw stable carbon and nitrogen isotope data from human bone collagen

61 2 F3-E44 11.4 0.2 15.4 0.6 -18.3 0.07 62 2 F3-E44 11.4 0.2 13.8 0.5 -18.3 0.07 63 2 F3-E45 13.0 0.2 19.4 0.8 -17.3 0.07 64 2 F3-E46 12.9 0.2 19.7 0.8 -17.2 0.07 65 1 F3-E46 12.9 0.2 19.7 0.8 -17.2 0.07 66 2 F3-E46 12.7 0.1 15.2 0.2 -16.8 0.04 66 2 F3-E47 13.8 0.2 12.6 0.5 -15.2 0.07 67 1 F3-E48 8.3 0.1 16.4 0.2 -20.5 0.04 68 2 F3-E49 14.3 0.2 17.8 0.7 -15.3 0.07 69 2 F3-E49 14.4 0.2 18.5 0.7 -15.3 0.07	41.4 2.5 37.1 2.2 49.4 3.0 51.0 3.1	3.1 3.1 3.0		
62 2 F3-E44 11.4 0.2 13.8 0.5 -18.3 0.07 63 2 F3-E45 13.0 0.2 19.4 0.8 -17.3 0.07 64 2 F3-E45 13.0 0.2 19.4 0.8 -17.3 0.07 65 1 F3-E46 12.9 0.2 19.7 0.8 -17.2 0.07 65 1 F3-E46 12.7 0.1 15.2 0.2 -16.8 0.04 66 2 F3-E47 13.8 0.2 12.6 0.5 -15.2 0.07 67 1 F3-E48 8.3 0.1 16.4 0.2 -20.5 0.04 68 2 F3-E49 14.3 0.2 17.8 0.7 -15.4 0.07 68 2 F3-E49 14.4 0.2 18.5 0.7 -15.3 0.07	37.1 2.2 49.4 3.0 51.0 3.1	3.1 3.0		
63 2 F3-E45 13.0 0.2 19.4 0.8 -17.3 0.07 64 2 F3-E46 12.9 0.2 19.7 0.8 -17.2 0.07 65 1 F3-E46 12.7 0.1 15.2 0.2 -16.8 0.04 66 2 F3-E47 13.8 0.2 12.6 0.5 -15.2 0.07 67 1 F3-E48 8.3 0.1 16.4 0.2 -20.5 0.04 68 2 F3-E49 14.3 0.2 17.8 0.7 -15.4 0.07 69 2 F3-E49 14.4 0.2 17.8 0.7 -15.4 0.07	49.4 3.0 51.0 3.1	3.0		
64 2 F3-E46 12.9 0.2 19.7 0.8 -17.2 0.07 65 1 F3-E46 12.7 0.1 15.2 0.2 -16.8 0.04 66 2 F3-E47 13.8 0.2 12.6 0.5 -15.2 0.07 67 1 F3-E48 8.3 0.1 16.4 0.2 -20.5 0.04 68 2 F3-E49 14.3 0.2 17.8 0.7 -15.4 0.07 69 2 F3-E49 14.4 0.2 18.5 0.7 -15.3 0.07	51.0 3.1			
65 1 F3-E46 12.7 0.1 15.2 0.2 -16.8 0.04 66 2 F3-E47 13.8 0.2 12.6 0.5 -15.2 0.07 67 1 F3-E48 8.3 0.1 16.4 0.2 -20.5 0.04 68 2 F3-E49 14.3 0.2 17.8 0.7 -15.4 0.07 69 2 F3-E49 14.4 0.2 18.5 0.7 -15.3 0.07		3.0	12.8	-17.0
66 2 F3-E47 13.8 0.2 12.6 0.5 -15.2 0.07 67 1 F3-E48 8.3 0.1 16.4 0.2 -20.5 0.04 68 2 F3-E49 14.3 0.2 17.8 0.7 -15.4 0.07 69 2 F3-E49 14.4 0.2 18.5 0.7 -15.3 0.07	42.0 1.3	3.2		
67 1 F3-E48 8.3 0.1 16.4 0.2 -20.5 0.04 68 2 F3-E49 14.3 0.2 17.8 0.7 -15.4 0.07 69 2 F3-E49 14.4 0.2 18.5 0.7 -15.3 0.07	34.2 2.0	3.2		
68 2 F3-E49 14.3 0.2 17.8 0.7 -15.4 0.07 69 2 F3-E49 14.4 0.2 18.5 0.7 -15.3 0.07	44.8 1.3	3.2		
69 2 F3-F49 14.4 0.2 18.5 0.7 -15.3 0.07	46.3 2.8	3.0	14.4	-15.4
05 2 15 245 14.4 0.2 10.5 0.7 15.5 0.07	48.5 2.9	3.1		
70 1 F3-E50 11.1 0.1 14.6 0.2 -18.8 0.04	38.1 1.1	3.0		
71 2 F3-E51 12.1 0.2 15.2 0.6 -17.6 0.07	40.7 2.4	3.1		
72 2 F3-E53			double drop	
73 2 F3-E53 13.2 0.2 16.4 0.6 -17.3 0.07	44.9 2.7	3.2		
74 2 F3-E55 14.5 0.2 16.3 0.6 -15.0 0.07	42.7 2.6	3.1		
75 1 F3-E56 9.1 0.1 14.7 0.2 -14.3 0.04	41.0 1.2	3.2		
76 2 F3-E57 10.0 0.2 16.2 0.6 -13.9 0.07	43.1 2.6	3.1		
77 2 F3-E58 17.2 0.2 14.2 0.6 -13.0 0.07	40.1 2.4	3.3		
78 2 F3-E59 16.6 0.2 14.4 0.6 -14.0 0.07	40.0 2.4	3.2	16.6	-13.8
79 1 F3-E59 16.6 0.1 16.2 0.2 -13.6 0.04	45.2 1.4	3.2		
80 2 F3-E60 13.2 0.2 15.9 0.6 -17.3 0.07	43.5 2.6	3.2	13.4	-17.2
81 1 F3-E60 13.5 0.1 15.7 0.2 -17.0 0.04	44.9 1.3	3.3		
82 1 F3-E61 12.5 0.1 15.8 0.2 -17.7 0.04	44.5 1.3	3.3		
83 2 F3-E63			double drop	
84 1 F3-E64 16.1 0.1 15.7 0.2 -14.2 0.04	43.7 1.3	3.2		
85 2 F3-E65 14.6 0.2 14.1 0.5 -17.2 0.07	38.6 2.3	3.2	14.5	-17.3
86 2 F3-E65 14.3 0.2 15.1 0.6 -17.4 0.07	42.9 2.6	3.3		
87 2 F3-E66 7.0 0.2 18.6 0.7 -20.6 0.07	47.4 2.8	3.0	7.1	-20.5
88 2 F3-E66			double drop	
89 1 F3-E66 7.2 0.1 15.4 0.2 -20.4 0.04	42.2 1.3	3.2		
90 2 F3-E67 10.0 0.2 18.2 0.7 -16.5 0.07	46.2 2.8	3.0		
91 1 F3-E68 15.6 0.1 14.1 0.2 -13.7 0.04	39.4 1.2	3.3		
92 2 F3-E69 14.7 0.2 14.5 0.6 -15.4 0.07	40.2 2.4	3.2	14.8	-15.3
93 1 F3-E69 14.8 0.1 15.3 0.2 -15.1 0.04	43.9 1.3	3.3		
94 2 F8-E01 9.3 0.2 14.4 0.6 -16.5 0.07	38.1 2.3	3.1		
95 1 F8-E02 9.5 0.1 16.7 0.2 -19.8 0.04	47.9 1.4	3.3		
96 2 F8-E03 9.0 0.2 17.3 0.7 -19.0 0.07	46.0 2.8	3.1		
97 2 F8-E04 10.6 0.2 16.9 0.7 -17.7 0.07	45.1 2.7	3.1	10.6	-17.8
98 2 F8-E04 10.6 0.2 16.8 0.7 -17.8 0.07	44.2 2.7	3.1		
99 2 F8-E05 9.6 0.2 16.7 0.7 -18.4 0.07	43.5 2.6	3.0		
100 2 F8-E06 8.9 0.2 16.3 0.6 -19.5 0.07	42.7 2.6	3.1	8.9	-19.6
101 2 F8-E06 8.8 0.2 16.7 0.6 -19.6 0.07	46.2 2.8	3.2		

	Α	В	С	D	E	F	G	н		J
1	sample	d18Oavg	std2	d13Cavg	std1	Average of replicates				
2	F12 E01	-7.23	0.29	-9.13	0.13	0	с			
3	F2 E02	-5.69	0.26	-8.37	0.10		_			
4	F3 E55	-5.85	0.50	-7.64	0.24					
5	F3 E01	-6.52	0.56	-8.39	0.20					
6	F3 E03	-6.39	0.29	-7.55	0.14					
7	F3 E04	-4.58	0.31	-8.47	0.18					
8	F3 E05	-6.63	0.47	-6.73	0.19					
9	F3 E06	-6.94	0.27	-8.19	0.12					
10	F3 E07	-5.75	0.36	-9.48	0.21	-5.45	-9.53			
11	F3 E07	-5.15	0.40	-9.59	0.19					
12	F3 E09	-8.09	0.39	-7.51	0.16					
13	F3 E10	-7.91	0.41	-7.76	0.19	6.72	7.00			
14	F3 E12	-0.82	0.42	-7.41	0.14	-0.73	-7.02			
15	F3 E12	-0.04	0.28	-7.65	0.20					
17	F3 F14	-6.93	0.28	-8.01	0.11	-6.69	-9 50			
18	F3 F14	-6.46	0.26	-10.19	0.12	0.05	5.50			
19	F3 E15	-6.60	0.41	-7.54	0.18					
20	F3 E16	-7.16	0.48	0.45	0.20					
21	F3 E18	-7.12	0.33	-5.32	0.17					
22	F3 E19	-8.32	0.33	-7.00	0.18					
23	F3 E20	-8.66	0.35	-6.85	0.15					
24	F3 E21	-5.11	0.38	-7.98	0.11		Radiocarbo	n Dating		
25	F3 E22	-6.68	0.29	-7.90	0.13		Samples exc	luded from	m O isotope	analysis.
26	F3 E23	-5.53	0.33	-7.69	0.55		F2E1			
27	F3 E24	-4.32	0.40	-6.48	0.14		F3-E2			
28	F3 E25	-6.89	0.47	-7.55	0.23		F3-E17			
29	F3 E26	-6.70	0.53	-7.31	0.26		F3-E31			
30	F3 E27	-5.36	0.32	-8.06	0.16		F3-E68			
31	F3 E28	-7.95	0.52	-7.49	0.20		F8-E3			
32	F3 E29	-7.21	0.59	-7.34	0.31					
33	F3 E30	-5.20	0.30	-9.03	0.29					
35	F3 F33	-5.85	0.42	-8.55	0.20					
36	F3 F34	-6.73	0.31	-8.13	0.13					
37	F3 E35	-6.13	0.33	-6.53	0.13					
38	F3 E36	-4.86	0.58	-6.95	0.22					
39	F3 E37	-7.38	0.26	-7.99	0.11					
40	F3 E38	-7.25	0.43	-6.07	0.18					
41	F3 E39	-6.97	0.34	-9.81	0.18					
42	F3 E40	-6.58	0.32	-7.97	0.12					
43	F3 E41	-4.22	0.25	-8.25	0.11					
44	F3 E42	-5.01	0.47	-8.53	0.23					
45	F3 E43	-5.26	0.32	-8.42	0.16					
46	F3 E44	-5.89	0.44	-8.86	0.21					
47	F3 E45	-6.55	0.49	-8.14	0.24					
48	F3 E46	-7.39	0.41	-8.70	0.23					
49	F3 E47	-5.59	0.50	-0.09	0.39					
50	F3 F40	-7.55	0.44	-3.50	0.20					
52	F3 F50	-7.15	0.45	-7.98	0.18					
53	F3 E51	-4.67	0.53	-8.03	0.23					
54	F3 E53	-6.31	0.28	-8.17	0.13					
55	F3 E56	-6.66	0.35	-5.09	0.13					
56	F3 E57	-6.35	0.29	-5.79	0.17					
57	F3 E58	-4.91	0.41	-5.72	0.12					
58	F3 E59	-5.57	0.32	-6.78	0.14					
59	F3 E60	-6.20	0.40	-7.78	0.18					
60	F3 E61	-5.90	0.31	-8.89	0.11					
61	F3 E63	-6.22	0.30	-4.45	0.14					
62	F3 E64	-4.65	0.50	-7.97	0.16					
63	F3 E65	-6.82	0.27	-7.54	0.10		0.45			
64	F3 E00	-6.02	0.47	-8.27	0.24	-5.72	-8.15			-
65	F3 E00	-5.41	0.22	-6.03	0.09					
67	F3 E60	-0.54	0.42	-7.12	0.13					
68	F8 F01	-3.00	0.20	-6.67	0.16	-6.01	-6.74			
69	F8 F01	-6.67	0.28	-6.81	0.16	-0.51	-0.74			
70	F8 E02	-7.00	0.39	-8,26	0.20					
71	F8 E04	-7.52	0.45	-7.90	0.22					
72	F8 E05	-7.41	0.31	-8.49	0.11					
73	F8 E06	-5.88	0.28	-7.99	0.13					

Raw stable carbon and oxygen isotope data from human bone apatite