Foraging to Farming: Diet and health on the frontier of maize agriculture in pre-Columbian Central Chile — insights from stable isotope analysis, radiocarbon dating, and dental palaeopathologies



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For my father, Jonathan Swift,
who encouraged me to believe the sky was the limit
—and gave me every reason to aim for it.

ABSTRACT

This thesis investigates the transition to maize agriculture in the Aconcagua and La Ligua Valleys of Central Chile, focusing on synchronic and diachronic variations in diet, the timing of significant socio-cultural and technological shifts, including the adoption of maize agriculture and the arrival of the Inka Empire, and the impact of the transition to maize agriculture on human dental health. Integrating stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$), radiocarbon dating and dental palaeopathological data, this thesis has reconstructed dietary patterns of the pre-Columbian inhabitants of the Aconcagua and La Ligua Valleys in Central Chile, examined the consequences of dietary change on dental health, and refined the chronology of these valleys in the late Holocene, specifically from the Early Ceramic Period through until the Late Period (from ca. 300 cal BC to cal AD 1532).

The period from ca. 300 cal BC to cal AD 1532 saw considerable dietary variability, which was related more to geographic location (inland or coastal sites) and diachronic trends than to cultural affiliations. Inland diets ranged from those dependent entirely on C_3 resources and low levels of animal protein, to those heavily dependent on C_4 and maize as a staple crop. Coastal diets were supplemented with low-trophic-level marine resources while also consuming terrestrial resources, including maize. The adoption of maize as a regular dietary resource likely occurred ca. cal AD 450-600, increasing to heavy dependence by ca. cal AD 1300-1400. Among the later agro-pastoralists, stable isotope data revealed differences in maize consumption between males and females, suggesting a broader social significance of maize beyond its economic utility.

The transition to maize agriculture had pronounced negative effects on human dental health with an increase observed in dental caries, ante-mortem tooth loss and periapical lesions. The cause of this decline in oral health likely goes beyond the increase in cariogenic foods, such as maize, and is also affected by biological differences between the sexes in terms of susceptibility to dental lesions as well as population growth and increasing fertility rates that accompany the transition to agro-pastoralism.

Finally, new radiocarbon dating has refined the chronology of these valleys and identified diachronic trends in the frequency of burials at the large cemetery sites of Estadio de Quillota and Valle Hermoso, consisting of an earlier (~387 cal BC to cal AD ~322) and a later (cal AD ~1245 to ~1423) phase of use and challenging the current interpretation of continuous use at these sites. Bayesian modelling of the chronological data also provided new evidence that the Inka Empire commenced its southward expansion up to a century earlier than suggested by the traditional Inka chronologies, with evidence of Inka influence having arrived in the Aconcagua Valley by the late 14th or early 15th century.

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CHAPTER 1: INTRODUCTION

1. Introduction

In human history, the adoption and intensification of agriculture mark significant milestones, often heralding profound shifts in social, economic, and cultural landscapes. Across the globe, the transition to agriculture precipitated far-reaching changes in human lifeways, diet and health. In the Americas, maize was the dominant cereal crop and its appearance in the archaeological record is an important indicator of agricultural expansion, often concomitant with social and political developments. The Southern Andes, including Western Argentina and the Central to Central-South of Chile, was the final region in South America to adopt cultivation of pre-Hispanic crops (Gil 2003) and home to some of the southern-most agriculturalists of the Americas, and indeed the world.

In the context of Central Chile the arrival of maize occurred relatively late, around ca. AD 200-800 (Falabella et al. 2007). The subsequent intensive farming and use of this staple crop is linked to social and political transformations in the region along with the burgeoning influence of the Inka Empire into the southern reaches of their Empire (ca. AD 1450). By the time of Spanish invasion (AD 1532), the strategic significance of Central Chile's Aconcagua Valley was apparent as an area of economic surplus, with the valley supporting irrigated agriculture, an abundance of maize, and productive gold mines (Valdivia 1991 [1555]; Vivar 1988 [1558]).

The fertile and mineral rich river valleys of Central Chile, with the Pacific Ocean in the West and a highland pass over the Andes in the East, were and important frontier zone for cultural exchange, agricultural development and Inka imperial expansion in late prehistory (Coros and Coros 1999; Falabella et al. 2016b; Uribe and Sánchez 2016). Despite the economic, political and strategic significance of this region, a majority of previous bioarchaeological research has focussed on adjacent areas to the north, east and south, leaving the Aconcagua and the neighbouring La Ligua river valleys of Central Chile relatively understudied. This thesis addresses this gap by examining the introduction and intensification of maize agriculture in Central Chile

and its impact on the diet and health of pre-Columbian populations. Chronological, isotopic and osteological approaches are integrated to provide insight into the complexities surrounding the adoption of maize agriculture, thereby contributing to a deeper understanding of Central Chile's prehistoric cultural development. The timing and consequences of the adoption of maize agriculture are evaluated using stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopic analyses alongside radiocarbon dating of human bone collagen, as well as dental indicators of oral health. By examining variations in diet across the diverse geographic and cultural settings of the Aconcagua and La Ligua Valleys, this thesis examines questions around the timing of the transition to maize agriculture, the pace and intensity with which this staple crop was adopted, and the impact of these changes on human oral health.

Another fundamental aspect of this thesis lies in establishing an initial chronological framework for some of the sites in this region, notably the Estadio de Quillota (EDQ) cemetery site in the Aconcagua Valley and Valle Hermoso in the La Ligua Valley. Existing chronological data for the Aconcagua and La Ligua Valleys is lacking, with very few radiocarbon dates available for these large river valley systems. This research establishes a preliminary radiocarbon chronology for some of the key sites in these valleys, while also utilising Bayesian modelling of radiocarbon dates, alongside stable isotope analysis, to shed light on variations in subsistence strategies over time, as well as the timing of the socio-political influences such as the arrival of the Inka Empire.

2. Aims and Hypotheses

The combination of stable isotopic and osteological analyses provides a method for quantifiable and informative insight into the adoption and economic importance of maize on the southern periphery of agriculture in the Americas. Osteological information regarding biological profile, health and nutritional status are used alongside the results of the isotopic analyses to reconstruct human dietary patterns and subsistence strategies and the effect any changes in diet, specifically relating to the incorporation of maize as an economic resource, had on the oral health of these populations. Furthermore, radiocarbon dating is

used to provide better chronological resolution in general, and to narrow down the timing of important economic and socio-political transitions in this region, being the adoption and intensification of maize agriculture, and the expansion of the Inka Empire to Central Chile.

2.1 AIMS

Specific objectives of this research are to:

1) Reconstruct and examine variability in diet across geographic, cultural and temporal settings.
    a. Determine when and among which groups maize was first incorporated into the diet in Central Chile.
    b. Ascertain whether the transition to maize agriculture was rapid or gradual.
2) Identify changes in the importance of maize as an economic resource.
    a. Make inferences about whether maize was solely an economic staple, or if differential access to maize within sites implies other significance as a ritual or luxury food. More specifically, seek to examine differential access based on sex.
3) Understand how the adoption of maize agriculture impacted oral health.
    a. Explore the relationship between diet, specifically maize consumption, and indicators of oral health such as dental caries, ante-mortem tooth loss and periapical lesions.
    b. Examine variability in dental lesions between sexes across different dietary categories, before and after the adoption of maize as a dietary staple.
4) Improve the radiocarbon chronology for the prehistory of the Aconcagua and La Ligua valleys with particular reference to two major transitions: the spread of maize agriculture, and the arrival of Inka influence.
    a. Establish a radiocarbon chronology for Estadio de Quillota, the largest cemetery site in the Aconcagua Valley.
    b. Refine the timing for the expansion of maize agriculture in this region.
    c. Reevaluate the timing of the expansion of Inka influence into this region.

2.2 HYPOTHESES TO BE TESTED

1. Variations in diet occurred depending on geographic setting (coastal or inland) and the dietary importance of maize increased over time.

Isotopic studies from the Maipo-Mapocho and Cachapoal rivers of Central Chile suggest an intensification of maize agriculture with inclusion of C_4 resources (maize being the only dominant C_4 foodstuff in Central Chile) increasing from the Early Ceramic Period (ca. 400 BC-ca. AD 1000-1200) and peaking during the Late Intermediate Period (ca. AD 1000/1200-1350/1450), before regressing slightly during the Late Period (ca. AD 1350/1450-1536)) (Falabella et al. 2007; Falabella et al. 2008; Sanhueza and Falabella 2010). Isotopic and archaeological evidence from coastal sites suggests a continuous use of low-trophic-level marine resources, alongside and increasing inclusion of maize during the Late Intermediate Period (Falabella and Sanhueza 2019). It is hypothesised the dietary importance of maize shows similar temporal and geographic fluctuations in the Aconcagua and La Ligua valleys.

1.a. Maize arrived in the Aconcagua and La Ligua Valleys approximately coeval with its first appearance elsewhere in Central Chile.

The La Ligua and Aconcagua River valleys were a transitory zone of innovation during prehistory, transitioning from the Atacama Desert of the north into the more fertile valleys of Central Chile. The adoption of maize is hypothesised to be approximately contemporaneous with that of the neighbouring Maipo-Mapocho and Cachapoal rivers of Central Chile, where existing isotopic evidence suggests maize first entered food systems between about ca. AD 200-800 during the Early Ceramic Period Period (ca. 400 BC-ca. AD 1000-1200). This was followed by a more robust adoption of maize agriculture with inclusion of C_4 resources in the diet reaching a peak during the Late Intermediate Period (ca. AD 1000/1200-1350/1450) (Falabella et al. 2007; Falabella et al. 2008).

1.b. The transition to maize agriculture was gradual.

Isotopic research from the northern regions of Chile has demonstrated that the shift from hunting and gathering to incipient and then intensive agriculture was likely to have been a gradual process (Sanhueza and Falabella 2010; Santana-Sagredo et al. 2015b). Archaeological evidence from Central Chile similarly suggests a gradual transition with evidence of some cultigens appearing in Archaic contexts (Planella and Tagle 2004; Planella 2005; Planella et al. 2005), but a persistence of hunting and gathering into various Early Ceramic Period contexts (Cornejo and Sanhueza 2003). It is hypothesized that the adoption of maize agriculture was also a gradual process in the Aconcagua and La Ligua valleys. If so, isotopic results should demonstrate a slow replacement of C_3 resources in the diet, signified by gradually increasing $\delta^{13}C$ values when compared with new radiocarbon dates for the samples studied.

2. Maize was not just an economic staple, but also served as a luxury or ritual food at different times.

Previous researchers of maize use in the Americas have attempted to define the differential use of the resource according to intra-population parameters such as age, sex, and social status (e.g. Reber 2006; Ubelaker et al. 1995). Maize is held to have had high ritual significance and symbolic associations in Andean archaeology, with links to fertility, feasting and chicha production indicating a socio-cultural importance of this resource that extends beyond its role as a staple food (Blake 2015). Evaluation of any differences in maize consumption within groups, particularly those from the larger cemeteries included in this study (such as Estadio de Quillota and Valle Hermoso), according to variables such as age, sex, and burial type, may support inferences about whether maize was considered a luxury food, a ritual food, a staple, or a low status item in the prehistory of Central Chile.

3. Adoption of maize agriculture deleteriously impacted human dental health.

There is considerable evidence from the palaeopathological literature that the transition to agriculture often had a negative impact on human health. These observations have continued to be substantiated in the bioarchaeological literature, demonstrating that the transition to agriculture frequently coincided with

deteriorating health, as represented by palaeopathological indicators such as increased dental caries, greater prevalence of skeletal markers of physiological 'stress' or nutritional deficiency, and reduced stature (Cohen and Armelagos 2013; Pinhasi and Stock 2011; Tiesler 2022). The transition to agriculture often narrows the availability of resources to reliance on one or a limited number of crops, resulting in a carbohydrate-rich diet of reduced nutritional value (Emerson et al. 2005; Larsen 1997; Mays 1998; Pinhasi and Stock, 2011). Increased sedentism and urbanisation accompanying the adoption of agriculture can also result in poorer standards of sanitation and an increase in communicable disease (Armelagos et al. 1991; Cohen and Armelagos 1984; Cohen and Armelagos, 2013; Pinhasi and Stock, 2011; Tiesler, 2022). Such dietary changes and their social effects are registered in human skeletal remains in the form of pathological lesions and can be particularly apparent in populations with a maize-based agriculture (Armelagos et al. 1991; Cohen and Armelagos 1984; Cohen and Armelagos, 2013; Emerson et al. 2005; Tiesler, 2022). Of particular use are pathological conditions in the dentition, such as caries, ante-mortem tooth loss and periapical lesions. It is hypothesised that a pattern of declining oral health, as assessed by these osteological indicators, will be observed in the Aconcagua and La Ligua valleys after the introduction of maize in the diet. It is expected that this will be reflected as an increase in the frequency of dental caries, AMTL and periapical lesions alongside the increasing inclusion of maize in the diet as determined by stable isotope analysis and higher $\delta^{13}C$ values from human bone collagen.

3.a Females will be impacted by dental health conditions with higher frequency than males, especially after the adoption of maize agriculture.

Generally, females experience higher rates of dental caries compared to males. This pattern has been observed across various cultures, subsistence strategies and chronological periods (Bertilsson et al. 2021; Bonsall 2014; Carvalho et al. 2019; Lopez et al. 2012; Lukacs and Thompson 2008; Namal et al. 2008; Walter et al. 2016; Willis and Oxenham 2013) and is also evident in modern clinical data (Carlos and Gittelsohn 1965; Ferraro and Vieira 2010; Galvão-Moreira et al. 2018; Shaffer et al. 2015). Although some exceptions exist (Esclassan et al. 2009; Šlaus 2000; Trombley et al. 2019), bioarchaeologists often attribute these sex-

based difference in dental caries to dietary variations and differential access to resources between males and females (Larsen, 1997; Hillson, 2008).

However, it has been suggested that this view of dental caries being a direct reflection of diet is overly simplistic and does not fully account for the multifactorial nature of caries pathogenesis (Marklein et al. 2019). Other factors such as sex-based differences in oral biology and differing levels in the hormone oestrogen, which is positively correlated with the development of dental caries, also play a role in the development of dental pathologies (Delma, 1955; Liu and Lin, 1973; Laine et al., 1988).

The transition to agriculture in pre-history not only brought about significant dietary changes, but also had broader impacts, referred to as the Neolithic Demographic Transition in the Old World, including increased sedentism, population growth and increased fertility and mortality rates (Bocquet-Appel and Naji 2006). Lukacs (2008) argues that a higher prevalence of dental caries in females should be expected in agricultural populations due to a concomitant increase in fertility rates and the biological impact this has on women, including longer periods with increased oestrogen levels, which in turn pre-disposes them to poorer oral health. It is hypothesised that in keeping with these observations, females will have a higher prevalence of the measured dental pathologies than males across all temporal periods examined. Furthermore, an even greater gap between rates of dental caries in females compared to males should be expected among those with maize-based diets, due not only to the transition to a more cariogenic diet, but also to the associated demographic changes associated with this transition in lifeways.

4. The large cemetery site at Estadio de Quillota in the Aconcagua Valley was in continuous use from the Early Ceramic Period until the Late Period.

The largest known pre-Columbian cemetery site within the Aconcagua Valley, Estadio de Quillota, is presumed to have been in relatively continuous use from at least the beginning of the Early Ceramic Period (ca. 300 BC), through until the Late Period when the region came under Inka influence (ca. AD 1450-1536)

(Didier and Ávalos 2009a; 2009b; Gajardo-Tobar and Silva 1970). However, much of this site was disturbed and important contextual information was lost during rapid excavation of the cemetery prior to encroaching construction at EDQ. Likewise, limited radiometric dating exists for EDQ, which has been described as one of the most important sites for the archaeology of Central Chile (Ávalos and Saunier 2011). It is hypothesised that new AMS radiocarbon dates on human bone collagen will reflect a pattern of use spanning from the Early Ceramic Period until the Late Period for EDQ. Establishing an initial radiocarbon chronology for EDQ will also provide a framework for the Aconcagua River valley system and when combined with stable isotope data will help in evaluating whether any dietary variability associated with synchronic communities with distinct dietary practices, or diachronic shifts in dietary patterns and subsistence strategies.

4.a. The influence of the Inka Empire expanded into the Aconcagua Valley earlier than the traditionally held date of AD 1471.

The timing of the arrival of Inka influence in Central Chile, on the Empire's southern frontier, is traditionally cited to have occurred in AD 1471 (Rowe 1945). However, this is more recently accepted to have occurred by at least AD 1450 (Uribe and Sánchez 2016). Bayesian modelling of radiometric dates from other frontier regions of the Empire, such as Ecuador and Argentina, also indicate that the traditional chronology of Inka imperial expansion, which is based on Spanish historical accounts, may be inaccurate and need revisiting (Marsh et al. 2017; Ogburn 2012). It is hypothesised that new radiocarbon dates of Late Period burials from Estadio de Quillota associated with Local Inka Phase ceramics will clarify the transition between the Late Intermediate Period and the Late Period in Central Chile, which is marked by the arrival of Inka influence, and reveal that this shift occurred earlier than AD 1471.

3. Background

The study area for this thesis encompasses multiple cemetery sites along the courses of the Aconcagua and La Ligua river valleys of Central Chile (Figure 1). The samples for this study span the Early Ceramic Period through to the Late Intermediate and Late Periods (ca. 300 BC - cal. AD 1532), encompassing the initial

transition to and subsequent intensification of agriculture and the later expansion of Inka imperial influence (Table 1). Although the transition to farming maize, as one of the primary economic staples in the Western hemisphere, is an enduring topic of research in American archaeology, there is a dearth of knowledge about this change in the Aconcagua and La Ligua river valleys. Previous Central Chilean archaeological research, including isotopic studies, has concentrated on the Maipo-Mapocho basin around Santiago and the Cachapoal river to the south, with little focus to the north of Santiago (Falabella et al. 2016b). As such, patterns of maize use are not yet known in the study area of the Aconcagua and La Ligua Valleys.

There have similarly been no large-scale palaeopathological studies in Central Chile examining the impact of the transition to agriculture on human health. Most bioarchaeological research has focused on the arid regions in the north of the country, where diet and subsistence strategies were governed by the extremely harsh environmental conditions of the Atacama Desert (Allison 1984; Pestle et al. 2021; Roberts et al. 2013; Santana-Sagredo et al. 2016; Santana-Sagredo et al. 2015a).

Central Chile, in contrast, has had a milder, Mediterranean-type climate for at least the past 3,000 years (Jenny et al. 2002; Villa-Martínez et al. 2003; Villagrán and Varela 1990). Its fertile river valleys were ideally suited for large-scale production of maize. Chroniclers from the post-contact period described the Aconcagua Valley in particular as an epicentre for the production of maize *"famous for the prodigious quantity of corn carried from it yearly"* (Frézier 1717, p.116).



Figure 1: Map of the study area showing location of sites from which human bone samples were collected for stable carbon and nitrogen isotope analysis, dental palaeopathological analysis and radiocarbon dating.

Age	Temporal Period	Cultural Phases
> ca. 1000 BC	Terminal Pleistocene	Palaeoindian
ca. 10000 – 300 BC	Archaic	Archaic Phases I, II, II & IV
ca. 400 BC – AD 1000/1200	Early Ceramic (ECP)	Initial Ceramic Communities (ca. 400 C – AD200) Bato (ca. AD200 – AD1000) Llolleo (ca. AD400 – AD1200)
ca. AD 1000/1200 – 1400/1450	Late Intermediate (LIP)	Aconcagua
ca. AD 1400/1450 – 1536 AD	Late (LP)	Aconcagua-Inka Diaguita-Inka

Table 1: Summary of archaeological periods and cultural phases relevant to the Aconcagua and La Ligua river valleys of Central Chile (adapted from Falabella et al. (2016b)).

3.1 ENVIRONMENT AND GEOGRAPHY

Central Chile extends from latitudes of 32 to 38 degrees south. It is a transitional area of fertile river valleys in a temperate Mediterranean climate, lying immediately between the world's driest desert to the north, the Atacama, and the wetter Araucaria forests (*Araucaria* spp.) of the Chilean lake district to the south (Sanhueza Riquelme 2016). Central Chile is geographically bounded by the Andes mountain range in the east, and the Pacific Ocean in the west.

The topography and an east to west cross-section of the region includes the coastal plain, the coastal mountain range (*cordillera de la Costa*), the Central Valley and the Andes mountain range (*cordillera de los Andes*) (Figure 2). The region is intersected by transverse river valleys originating in the high Andes to the east, traversing the central valley, and flowing out through the coastal plain to the Pacific Ocean in the west. The coastal plain at these latitudes is intermittent, being interrupted by the coastal mountain range which usually lies around 25 to 50km inland, but periodically touches the coastline forming coastal cliffs around beaches.

The topography in Central Chile is distinctive, characterized by a continuous, broad longitudinal plain, lying at an average of 300-500 masl, between the coastal mountain range and the Andes. This is called the Intermediate Depression (*Depresión Intermedia*), also referred to as the Inland Valley and the Central Valley. The Central Valley is made up of the quaternary fluvial terraces of the various rivers that traverse it (Maldonado et al. 2016). These include the La Ligua and Aconcagua Rivers in the northernmost section (the Valparaíso Region) of Central Chile.

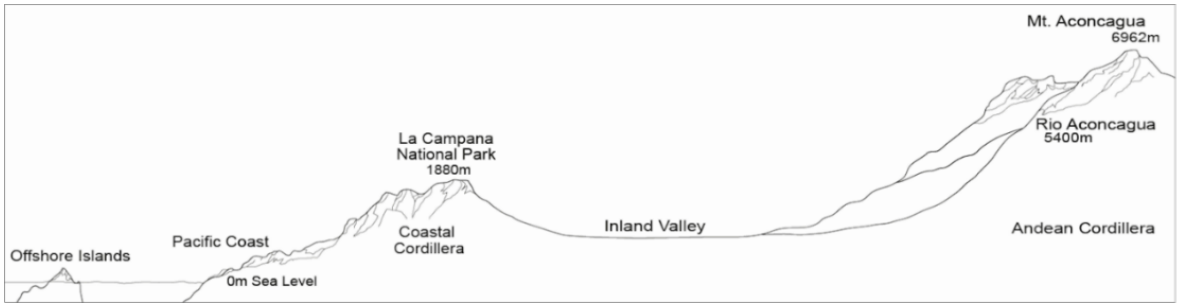


Figure 2: Cross-section (not to scale) of the Aconcagua Valley, demonstrating the topography from west to east, and the Inland Valley flanked by the coastal cordillera and the Andean cordillera.

Today, Central Chile is the most densely populated and economically productive region in the country. Nearly 40% of the national population resides in the Metropolitan and Valapraíso Regions (the Central Chilean region that makes up the study area for this project) (Instituto Nacional de Estadístícas 2017). The Mediterranean climate coupled with the fertile local soils contributes to the region's agricultural significance, supporting large orchards of economic crops such as avocado, as well as Chile's renowned wine industry (Armesto et al. 2007; Gardiazabal and Mena 2011; Mora 2019). Natural vegetation in this area is part of the Chilean matorral biome, characterised by drought-resistant shrubs and sclerophyllous trees, including a high proportion of endemic plant species such as peumo (*Cryptocarya alba*) and quillay (*Quillaja saponaria*) (Martín-Forés et al. 2012).

The relatively flat inland valley area made it attractive for human settlement in prehistory. Even today, the vast majority of the Chilean population is concentrated in this zone, which includes the country's major population centers of the modern capital city Santiago, the Valparaíso Region and the O'Higgins Region (InstitutoNacionaldeEstadísticas 2017). These modern geo-political districts incorporate the river basins of the Aconcagua and La Ligua (Valparaíso Region), the Maipo-Mapocho (Metropolitan Region) and the Cachapoal (O'Higgins Region). The higher density population and more extensive land development of Central Chile are major factors contributing to poorer preservation of human skeletal remains in this region, and also the sparsity of bioarchaeological research in this region compared to the north.

3.2 REGIONAL PREHISTORY

The archaeology of Central Chile is relatively underrepresented in the academic literature. This is in part due to environmental conditions that lead to poorer preservation of organic remains, particularly in comparison to the neighbouring Atacama Desert (with its excellent preservation of organic remains, including naturally mummified skin and hair), as well as its increased urbanization and industrial development compared to the rest of the country (Falabella et al. 2016a). The majority of human remains which have been recovered from Central Chile are highly fragmentary, limiting the extent of bioanthropological study. Within this region, where the deserts of the north give way to the greener landscape of Central Chile, comprising the three large fluvial basins of the Aconcagua, the Maipo-Mapocho and the Cachapoal, there are, nonetheless, some areas within the region that have been studied more extensively than others. The southern section of Central Chile, from the Maipo-Mapocho to the Cachapoal Basin has received more attention than the northern region of Central Chile, encompassing the Aconcagua and La Ligua Valleys.

Humans began to inhabit Central Chile during the late Pleistocene and various temporal and cultural traditions have been described for the subsequent human prehistory in this region (Falabella et al. 2016b; Núñez et al. 2016; Uribe and Sánchez 2016). The human skeletal remains subject to this research pertain specifically to the late Holocene, from the Early Ceramic Period (ca. 400 BC–AD 1000/1200), through the Late Intermediate Period (ca. AD 1000/1200–1350/1450) and up to the Late Period (ca. AD 1350/1450–1536).

3.2.1 Early Ceramic Period (ca. 400 BC - AD 1000 / 1200):

During the Early Ceramic Period, several cultural groups coexisted in Central Chile with different cultural identities and subsistence strategies. Some groups, such as the Initial Ceramic Communities and the Bato maintained traditional hunter-gatherer lifestyles while others, such as the Llolleo, began incipient agriculture (Falabella et al. 2016a).

Initial Ceramic Communities (ca. 400 BC – AD 200)

The Initial Ceramic Communities (ICCs) occupied the valleys and coast in Central Chile, typically along the main watercourses. They existed in autonomous, relatively independent family units. Their hunting and stone tool technology, such as long, triangular stemmed points, show continuity with the earlier Archaic Period of the region (Falabella et al. 2016a). They continued hunting and gathering and the exploitation of marine resources. However, they were also the first groups in Central Chile to regularly produce ceramics, usually small, thin-walled vessels in simple forms (Falabella et al. 2016a). The earliest ceramic pipes have also been attributed to this period. At some highland sites, archaeobotanical studies have identified evidence from macro and microfossils of incipient cultivation of quinoa (*Chenopodium quinoa*) (Planella and Tagle 2004; Planella et al. 2017; Planella Ortíz 2019; Sanhueza et al. 2003). Evidence of burial practices is limited, but grave goods have included pottery, sometimes intentionally broken, and a grinding stone, accompanying flexed burials that have been placed on their side (Falabella et al. 2016a).

Bato (ca. AD 200 - 1000)

The Bato and Llolleo cultural complexes are largely contemporaneous yet distinct groups within Central Chile during the Early Ceramic Period. The Bato cultural complex is believed to have arisen slightly earlier than the Llolleo. They shared some of the same areas in the Aconcagua Valley, the Santiago basin and the Maipo precordillera. However, the Bato people primarily occupied the zone to the west of the coastal Cordillera, with the majority of their sites located along the coast and concentrated mainly in the more northern part of Central Chile, particularly around the mouth of the Aconcagua River (Ávalos and Saunier 2011). In general, coastal Bato sites are noted as quite small, with limited stratigraphic depth. There are exceptions, such as the sites S-Bato 1 and Camino Internacional, which comprise expansive and deep middens indicating likely reuse and revisitation of these sites over long periods of time (Carmona et al. 2001). However, the generally small and shallow size of most coastal Bato sites has been interpreted as evidence that they retained a level of mobility along the coast (Falabella et al. 2016a). The presence of some Bato artefacts at inland Llolleo sites, such as Fundo Esmeralda, has been interpreted as evidence of contact with inland groups either by trade or seasonal migration (Ávalos 2007).

No social hierarchy has been identified for the Bato. Rather, they existed in small, mobile familial groups with shared technologies and material culture across the region (Falabella et al. 2016a). They largely maintained a hunter-gatherer lifestyle with some degree of territorial mobility. Their diet was based on wild C_3 plant resources, including native fruits, and the abundance of projectile points and camelid bones at Bato sites indicates a continued reliance on hunting (Carmona et al. 2001; Rivas and Gonzalez 2008). Coastal Bato groups also supplemented their diets with near-shore, low-trophic-level marine foods (Ávalos and Saunier 2011; Falabella et al. 2007; Falabella and Sanhueza 2019). However, the presence of grinding stones as well as archaeobotanical remains of quinoa and *curagua* (*Zea curagua* - a small, wild variety of maize native to Chile, also known as Valparaíso popcorn as it is a progenitor of modern popcorn (Santacruz-Varela et al. 2004)), particularly within inland Bato sites, also demonstrates their incipient use of, or access to, some early cultigens (Ávalos 2005; Planella and Tagle 2004; Santacruz-Varela et al. 2004).

Bato burial offerings typically included mollusc shells, camelid bones, pot sherds, and sometimes ceramic pipes or personal ornaments such as beads, pendants and *tembetá* (a stone labret) (Falabella et al. 2016a; Sanhueza Riquelme 2016). Burials were usually placed on their side in a flexed or hyper-flexed position. However, some have been recorded in a ventral, face down, position with their legs flexed behind them (Sanhueza 2020).

Llolleo (ca. AD 400 – 1200)

The Llolleo co-existed alongside the Bato within the Aconcagua valley, although they are regarded as more sedentary. An analysis of Bato and Llolleo ceramics has shown some shared technologies between the groups (Falabella et al. 2015). Unlike the Bato, who were present in the La Ligua valley, the Aconcagua valley represents the northern most limit of the Llolleo cultural complex, with no known Llolleo sites in the La Ligua valley. The Llolleo inhabited both the lowland river valleys, as well as coastal zones. Their habitation and cemetery sites were small and dispersed throughout the landscape, comprising one or two family units, and

without any apparent social hierarchies (Falabella et al. 2016a). They established occupation sites in the middle and upper sequence of the Aconcagua Valley, the Santiago Basin, the Rancagua Basin, as well as some limited coastal settlements, mainly surrounding the mouth of the Maipo River (Falabella et al. 2016a). Llolleo sites have been identified in the Santiago basin dating from c. AD450 to 1000. However, in the Aconcagua basin to the north, and the Cachapoal Basin to the south, some Llolleo sites persisted until c. AD1200 (Falabella et al. 2016a).

Archaeofaunal and archaeobotanical analysis of Llolleo sites in the Maipo-Mapocho basin have revealed an abundance of guanaco (*Lama guanicoe*) bones alongside a mixture of both wild and cultivated plant species (Planella and Tagle 2004; Sanhueza et al. 2003). Cultigens that have been identified in Llolleo contexts include native *curagua* maize (*Zea curagua*), beans (*Phaseolus* sp.), quinoa (*Chenopodium quinoa*), squash (*Curcurbita* sp.), and gourds (*Lagenaria* sp.) (Planella et al. 2014; Planella and Tagle 2004; Sanhueza et al. 2003). While guanaco bones are present at many sites, very little hunting equipment (such as projectile points) has been identified in Llolleo contexts. Similarly, at coastal Llolleo sites, middens contain the remains of in-shore marine resources, but no specialised technology for fishing has been identified. The scarcity of fishing gear and hunting equipment, alongside the regular presence of grinding stones and ceramics at these sites suggests that cultivating crops was becoming more important to the Llolleo than hunting large wild game (Falabella et al. 2016a).

The Llolleo are considered to have been sedentary, with different communities settling more-or-less permanently. This is demonstrated by raw materials for ceramics having been sourced locally, as well as the differences observed in Llolleo diet between distinct areas (the Maipo-Mapocho and Cachapoal Basins) (Falabella et al. 1995; Falabella et al. 2007). Their relative sedentism in the Maipo-Mapocho is also supported by evidence from stable oxygen isotope analysis of dental enamel and bone apatite suggesting that few adults had migrated from a different zone since their childhood (Falabella et al. 2007). Despite living in small, self-sufficient groups the Llolleo maintained a collective identity. This is supported by a consistent ceramic style and iconography across their region and evidence of large social or ceremonial gatherings at some

sites, such as La Granja in the Cachapoal basin, where over 1000 Llolleo ceramic pipes were recovered containing residues of psychoactive substances and tobacco (Sanhueza Riquelme 2016).

Llolleo mortuary practices included burying adults in a flexed position, and infants within large ceramic urns (Ávalos and Saunier 2011; Falabella et al. 2016a). Their burials were accompanied by ceramic offerings, usually jugs, which sometime contained remnants of maize, quinoa, squash and a yellow sediment suggesting the presence of *muday* (a mildly-alcoholic drink made from quinoa or corn flour) (Falabella et al. 2016a). Other grave goods include items such as stone bead necklaces and grinding stones (Sanhueza 2020).

Influences from the north

Within the La Ligua Valley in particular, some cultural influences have been observed from the immediately neighbouring semi-arid north. Evidence for El Molle and Las Animas cultural influence has been tentatively identified at the sites of Valle Hermoso, a central valley site in La Ligua, and Los Coiles 136, a coastal site to the north of the La Ligua river mouth (Ávalos and Rodriguez 1993; Becker et al. 1995). The El Molle were the first of the ceramic cultures from the semi-arid north. They domesticated llamas and practiced irrigated agriculture of various cultivars, including maize, beans, squash and cotton (Rivera 1999). El Molle was replaced by Las Animas, a culture thought to have derived from the Argentine side of the Andes, bringing with them new styles of ceramics and an advancement of metalworking technologies (Rivera 1999).

3.2.2 Late Intermediate Period (ca. AD 1000 / 1200 – 1400 / 1450)

Aconcagua Culture

The development of more intensified agriculture during what is identified as the Late Intermediate Period (LIP) started to appear among some Central Chilean groups around ca. AD 1000, but for others did not take place until around ca. AD 1200 (Falabella et al. 2016a). This period saw a complete socio-cultural change, with the appearance of new personal adornments, a change in lithic technology and use, and a change in ceramic production techniques (Falabella et al. 2016a). Changes were also observed in mortuary practices

(Sánchez 1993; Sánchez 1995). During this period, the dead were buried outside of habitation areas, usually in larger scale cemeteries. Bodies were often interred in an extended position and face down.

During the Late Intermediate Period, the Aconcagua rose as the dominant culture in Central Chile, establishing larger areas of habitation on the fluvial terraces of the transverse valleys. The Aconcagua cultural complex extended from the Aconcagua Valley in the north to the Cachapoal River in the south (Falabella et al. 2016a). People inhabited scattered hamlets, located along fluvial terraces or close to water sources. Occupation sites comprised a few residential units and areas for processing food as well as the production of lithics and pottery. Fields for cultivating crops were situated adjacent to habitation areas (Falabella et al. 2016a). Coastal sites in the LIP have been located at the mouth of river valleys, on coastal plains and around wetlands and coastal lagoons. The Aconcagua had a more hierarchical social structure compared to their predecessors (Falabella et al. 2016a). Some sex and age-based differences have been observed in diet and access to maize (Falabella et al. 2020), and also some differential mortuary practices (Sánchez 1993; Sánchez 1995).

While the Aconcagua preferentially inhabited the inland valleys, it is suggested that they may have also settled coastal areas and occupied inland camps on a seasonal basis (Ávalos and Saunier 2011; Falabella et al. 2003). Evidence of temporary encampments near sources of raw materials, or natural areas for hunting camelids has been described at inland sites (Cornejo and Galarce 2004; Pavlovic 2000). Limited seasonal movement has been supported somewhat by previous stable oxygen isotope ($\delta^{18}O$) analysis of human bone apatite and tooth enamel (Falabella et al. 2020). There is no indication of occupation in the areas above 1500 m asl, however, there is evidence of material culture from the Aconcagua reaching across the Andes to the eastern slopes (Cornejo and Sanhueza 2011; Falabella et al. 2001).

There was an increase in horticulture during the LIP, particularly in maize production. Dietary isotopic studies from the Maipo-Mapocho and Cachapoal Basins indicate a strong reliance on maize during the LIP (Falabella et al. 2007). Numerous other cultigens have been identified in LIP contexts in the Maipo-Mapocho Basin

including quinoa (*Chenopodium quinoa*), various squash (*Curcurbita* spp.), various beans (*Phaseolus vulgaris, Phaseolus lunatus, Phaseolus* spp.) and *madi* (Chilean tarweed [*Madia sativa*]) (Planella et al. 2014). Other indications of increasing domestication of edible plants includes larger grain sizes of cultivated quinoa, an increase in the size and variety of beans, as well as an increase in the size of maize kernels, variety of maize species and general ubiquity of maize at sites from this period (Belmar et al. 2013; Planella et al. 2014; Planella et al. 2013). A greater prevalence of grinding stones have also been recorded at LIP sites (Falabella et al. 2016a).

Archaeological deposits suggest that agricultural produce was supplemented with hunting and gathering of easily accessible local resources (Hermosilla et al. 2003; Planella et al. 2014). An increased consumption of guanaco (*Lama guanicoe*) is observed during this period, and possibly a change in the management of this animal. Guanaco bones are the most abundant faunal remains associated with LIP sites, with evidence they may have been temporarily pastured nearby to habitation sites, fed on maize stover and exploited for their fibre, hides and meat (Becker 1993; Tykot et al. 2009). Material culture associated with processing fibres and hides, such as spindle whorls, awls and needles have also been noted (Falabella et al. 2016a). Other faunal remains include foxes, some rodents, *coipus* (nutria), frogs and birds (Falabella et al. 2016a). Middens from coastal sites contain the remains of molluscs, marine mammals, near-shore species of fish, such as *corvina* (white sea bass [*Cilus gilberti*]), *merluza* (Chilean hake [*Merluccius gayi*]), and *jurel* (Pacific jack mackerel [*Trachurus symmetricus*]), and inter-tidal species such as *pejesapo* (Chilean clingfish [*Sicyases sanguineus*]) that can also inhabit brackish river mouths (Falabella et al. 2016a; Falabella et al. 1994).

Ceramics were produced locally, but their styles became more standardized across the Central Chilean region. However, the proportion of *Aconcagua Salmon* style pottery is lower in the sites further inland, around Los Andes and San Felipe (Falabella et al. 2003). This has been interpreted as the result of greater interaction with external groups, particularly at the sites closer to the Andes and the connecting roads across and along the highlands. Other artefacts from Aconcagua sites have included stone flutes, earrings, pendants and *clavas* (lithic insignias with a handle and head in the stylised form of a bird, some of which were

produced in a miniature form and included with sub-adult burials) (Ávalos and Saunier 2011; Falabella et al. 2016a). Metallurgical practices also developed during this period as evidenced by the presence of copper artefacts, such as fishhooks and jewellery, recovered from Aconcagua contexts (Latorre 2006). Bone instruments such as tubes, spatulas and spoons for the use of hallucinogenic substances have also been recorded in some Aconcagua contexts and differ from the pipes of the Early Ceramic Period (Gaete 1993).

Influences from the north

Around the same time, the Diaguita became the prominent culture of the semi-arid region in the north of Chile and continued to dominate Norte Chico until the Spanish conquest. The Diaguita were dedicated agro-pastoralists with a dual socio-political organisation with chiefdoms divided between coastal areas and the inland reaches for each of their river valleys (Rivera 1991). In relation to Central Chile, the Diaguita are generally only mentioned in the context of the Late Period. However, there is some question as to whether or not LIP settlements in the La Ligua region are part of the Aconcagua cultural complex at all (Avalos González et al. 1999; Durán and Planella 1989; Falabella et al. 2016a). The largest cemetery sites previously described in the La Ligua Valley, Valle Hermoso and Los Coiles 136, have not revealed evidence of Aconcagua material culture, but appear to be locally evolved and share some stylistic similarities in material culture with influences from the semi-arid north, particularly the Diaguita, as well as some similarities with groups from the Putaendo valley (Becker et al. 1995; Kaltwasser 1968; Rodríguez and Ávalos 1994; Rodriguez et al. 1993). At Escuela de Placilla, another cemetery in La Ligua, one Aconcagua burial context was identified, but otherwise the cemetery appears to reflect more localised cultural practices with influences from the Diaguita (Ávalos and Rodriguez 1993; Rodríguez et al. 1995; Saunier et al. 2007; Solé et al. 1994).

3.2.3 Late Period (ca. AD 1400 / 1450 – 1536)

Aconcagua-Inka and Diaguita-Inka

The Late Period in Central Chile is defined by the presence of Inka influence and acculturation in the region. The Aconcagua Valley of Central Chile held strategic significance in the Inka State (*Tawantinsuyu*) during the

Late Period as an administrative centre for the southern reaches of the Empire (de Góngora Marmolejo 2010 [1524-1575]; Mariño de Lobera 1970 [1580]; Valdivia 1991 [1555]; Vivar 1988 [1558]). It has been recently proposed that the upper basin of the Aconcagua may have been the initial focus of imperial activity and the point of diffusion for Inka expansion within Central Chile (Mundt and Marsh 2021). The local Aconcagua culture continued into the early stages of the Late Period, exhibiting signed of 'foreign' Diaguita and Inka influences in their material culture. The diversity observed in Late Period ceramic morphology and technology is interpreted as reflecting different degrees of local integration with *Tawantinsuyu,* where principles of exclusion and inclusion operated between the State and local communities (Dávila et al. 2018; Martínez 2011; Pavlovic et al. 2019).

Inka control of Central Chile is generally held to have been via indirect government (Hermosilla et al. 2005; Silva 1978; Stehberg 1995; Uribe 2000). A more defined hierarchy was implemented with social units headed by local *caciques*, and previously dispersed communities were organised into villages. It is argued that there was a two-phase integration of this region, with an initial arrival of Inka influence followed by a secondary phase of Imperial occupation (Alconini 2016; Dávila et al. 2018; Pavlovic et al. 2019). The initial phase of Inka influence involved various interactions with local populations, including the exchange of idea, material culture, political negotiations, and economic redistribution. The subsequent phase saw the integration of Central Chile into the Empire's southern frontier, marked by the emergence of Inka structures, such as *tambos* (state-owned lodgings on Inka roads), *qollqas* (storehouses), *pukaras* (fortified sites), and *huacas* (shrines). Burials in the Upper Basin were placed in vaulted tombs, and ceremonial sites have been located in the high Andes, including the frozen mummy from a *capacocha* (child sacrifice) near the peak of Mt Aconcagua (Fernández et al. 1999; Pavlovic et al. 2012; Troncoso 2004).

Inka hill forts can be found at various intervals along the Aconcagua River (Coros and Coros 1999; Sánchez Romero 2002; 2004; Troncoso et al. 2012). While these installations were some distance apart, they were connected via the Inka road network. An Inka road ran longitudinally through Central Chile at the foot of the Andean Cordillera, connecting to the Inka capital, Cusco, in the north and extending south towards modern

Santiago. A latitudinal crossroad also traversed the Andes at a high mountain pass above the headwater of the Aconcagua River, connecting the Aconcagua Valley, all the way from the Pacific Coast in the west, across the Andes and descending the eastern slopes to Mendoza, in Argentina (Uribe and Sánchez 2016).

Under the influence of the Inka Empire, various forms of production were increased, including mining, maize agriculture which was now irrigated, and the domestication of camelids (Uribe and Sanchez, 2016). Late Period sites have a notable abundance of plant remains, with a great diversity of taxa. This includes the appearance of more domesticates, such as potatoes (*Solanum tuberosum*), peppers (*Capsicum annuum*) and other tubers, which were previously unrecorded (Planella et al. 2014). Residue analysis of funerary pottery from the Maipo-Mapocho Basin revealed remnants of maize (*Zea mays*), quinoa (*Chenopodium quinoa*), kañiwa (*Chenopodium pallidicaule* - another hardy and protein-rich and edible grain from the same family as quinoa), potato (*Solanum tuberosum*), numerous varieties of beans (*Phaseolus* spp.) and other legumes (*Fabaceae* spp.), capsicum (*Capsicum* spp.), wild fruits of the Clusiaceae family, *algarrobo* (carob [*Prosopis chilensis*]), *maqui* (Chilean wine berry [*Aristotelia chilensis*]), herbs from the Lamiaceae family (*Lamiaceae* spp.) which includes mint, sage, rosemary and basil, *quilo* (wirevine - a native sarsaparilla with edible leaves and small fleshy fruit [*Muehlenbeckia hastulatal*]), varieties of purslane (*Portulaca* spp.), *molle* (Peruvian peppercorn [*Schinus* spp.]), and verbena (*Verbena* sp.) (Belmar et al. 2020; NationalResearchCouncil 1989). The abundance and frequency of maize recovered from LP sites is higher, suggesting an increase in scale of production and a shift to a different agricultural production modality (Planella et al. 2014; Rossen et al. 2010), aligning with Inka influence expanding to the region (Belmar et al. 2020).

The timing of the Inka expansion into the La Ligua/Aconagua region is equivocal. According to the traditional chronology of Inka expansion, there was a pre-Imperial phase in Cuzco from ca. AD 1200 to 1438, after which the Inka began conquering nearby neighbouring regions (Rowe 1944; 1945). The majority of expansion to the southern quarter of the Empire (*Collasuyu*) supposedly took place from AD 1471 to 1493, after incursions into most of the rest of the Empire. More recently, however, evidence has been growing to support a hypothesis that the Inka expanded toward their Southern limits several decades to a century before the AD

1471 to 1493 date of the traditional chronology (Betanzos 1987 [1551]; Cornejo 2014; Marsh et al. 2017; Sánchez Romero 2004).

4. Methodological Approach

The Aconcagua and La Ligua Valleys of Central Chile, while rich in cultural heritage and an abundant archaeological record, present unique challenges for bioarchaeological research. Unlike the hyper-arid north of Chile, where the preservation of human skeletal material is exceptional, Central Chile's wetter Mediterranean environment alongside extensive modern infrastructure and development, including the presence of the modern capital of Santiago de Chile, have led to significant ground disturbance, poorer preservation of archaeological sites and loss or destruction of important archaeological context. Indeed, much of the human skeletal material that has been excavated in Central Chile, and, in turn, much of the human skeletal material included in this research, is highly fragmentary, with limited contextual information available.

Despite these challenges, this thesis demonstrates the potential of bioarchaeological research to reconstruct past lifeways, prehistory, and cultural heritage, even in suboptimal conditions. While the lack of context does pose some limitations, the analysis of fragmentary remains can still yield valuable insights into important transitions in lifeways, dietary practices, subsistence methods, population health, and chronological frameworks, thereby re-establishing some context for such culturally significant, but highly disturbed and damaged human remains of the pre-Columbian populations of the Aconcagua and La Ligua Valleys. Using a combination of stable isotope analysis, osteological examination, dental palaeopathological analysis, and radiocarbon dating, this research provides a nuanced understanding of the complexities of human lifeways in this region.

The human skeletal collections examined and sampled for this research are held in four museums within the Aconcagua and La Ligua Valleys: Museo Histórico-Arqueológico de Quillota, Museo Historía Natural de Valparaíso, Museo La Ligua and Museo Arqueológico de Los Andes. The collections housed within these

museums pertain to various sites along the river valleys, from the Pacific coast to the foot of the Andean pre-cordillera (Table 2). Some of the sites from which the material was derived are cemetery complexes with varying levels of contextual information available from excavation reports (e.g. Estadio de Quillota, Fundo Esmeralda, Valle Hermoso, Los Coiles 136, La Ligua, Longotoma, El Membrillar, Arauco, Pueblo de Indios, Aspillaga I and II), and others are isolated finds resulting from salvage recovery.

			Number of Individuals			
Valley	**Setting**	**Site**	**Stable Isotope Analysis**	**Dental Palaeopath.**	**^{14}C Dating**	**Museum^**
Aconcagua	Coast	El Membrillar II	1	1		MHAQ
		Concon + Camino Internacional	3	3		MHNV
		S Bato 1	2	2		MHNV
		Villa Alemana	2	1		MHNV
	Inland	Aspillaga I	5	1		MHAQ
		Aspillaga II	8	4		MHAQ
		Calle Arauco	5	1		MHAQ
		Estadio de Quillota	113	78	17	MHAQ
		Fundo Esmeralda	12	12		MHAQ
		Las Chilcas	1	3		MHAQ
		Maltería	3	2		MHAQ
		Pueblo de los Indios	3	4		MHAQ
		Pocochay	2	1		MHNV
		Calle Ricardo Santa Cruz	7	5		MHNV
		Calle Larga	1			MLA
		Fundo Las Palmas	1	1	1	MLA
		Los Andes Sites:*				MLA
		Bicentenario	2			MLA
		Calle Esmeralda S1	1	1		MLA
		El Sauce	2	1	1	MLA
		Jumbo	1	1		MLA
		La Capilla Calle Larga	1			MLA
		Los Villares 1600	1			MLA
		Primera Quebrada	1			MLA
		Puente El Castillo	1		1	MLA
		Santa Rosa Tumulo 2	1			MLA
		Rinconada Sites:*				MLA
		Villa El Esfuerzo	1	1		MLA
		Villa Renacer 2	1	1		MLA
		San Esteban Sites:*				MLA
		Callejon Los Olivos	1	1		MLA

		Calle Los Reyes	3	2		MLA
		El Hijueral	1			MLA
		Los Placeres La Florida	1	1		MLA
		Sra Mura, La Florida	1	1		MLA
		San Felipe Sites:*				MLA
		Calle Padre Hurtado 1800	1			MLA
		Condominio Conjuillio Tocornal	1			MLA
		El Asiento Rio Putaendo	1			MLA
		San Vilches	1	1		MLA
La Ligua	Coast	Papudo	3	1		MHNV
		Conchales de Longotomá	1	1		MLL
		Dunos de Longotomá	1	1		MLL
		La Ligua	1	1		MLL
		Los Coiles 136	9	7		MLL
	Inland	Escuela de Placilla	21	14		MLL
		Quinquimo	1	1		MLL
		Valle Hermoso	26	21	15	MLL
Total			**256**	**177**	**35**	

Table 2: Sample numbers for each of the three specific methodologies, stable isotope analysis (n=256), dental palaeopathological analysis (n=177), and radiocarbon dating (n=35).

^MHAQ = Museo Histórico-Arqueológico de Quillota, MHNV = Museo Historía Natural de Valparaíso, MLA = Museo Arqueológico de Los Andes, MLL = Museo La Ligua.

**Sites within close proximity have been grouped under a subheading that corresponds to their representation on the map presented in Figure 1.*

4.1 RECONSTRUCTING DIET IN THE PAST

A number of methods are open to archaeologists for making interpretations about diet in past populations, both indirect and direct. Indirect methods generally draw from archaeobotanical analyses of floral remains and pollen or phytoliths, zooarchaeology of faunal remains, residue analysis of containers and tools, analysis of cultural artefacts associated with food gathering, hunting or production, and ethnoarchaeology (Metheny and Beaudry 2015; Peres 2023; Twiss 2019). These data can be limited by differential preservation and recovery, as well as possible contamination (in the case of pollen analysis). Indirect evidence of diet, or at

least nutrition, can also be interpreted from the human skeleton in terms of diseases associated with nutritional deficiencies, lines of growth arrest in long bones, and mean of statures of populations (Cohen and Armelagos 2013; Roberts and Manchester 2005; Steckel and Rose 2002). Moreover, a wealth of evidence can also be obtained from the dentition, which after all, interacts directly with the food a person consumes. Patterns of oral health including rates of dental caries, antemortem tooth loss (AMTL), and periapical lesions (including dental abscesses), among others can indicate changes in staple food sources and subsistence strategies.

Direct evidence of past diet can be derived from human gut contents, coprolites and stable isotope analysis of human tissues (Metheny and Beaudry 2015; Peres 2023; Twiss 2019). This research specifically employs the use of stable carbon and nitrogen isotopic ($\delta^{13}C$ and $\delta^{15}N$) analysis of human bone collagen. Stable isotope analysis of human remains provides direct evidence of past diet and has been increasingly used in palaeodietary reconstructions and to infer subsistence strategies (DeNiro and Epstein 1981; Lee-Thorp 2008; Roberts 2022; Vogel and van der Merwe 1977). Variations in stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios are passed through the food chain and recorded in the tissues of human consumers. Analysis of $\delta^{13}C$ and $\delta^{15}N$ from human bone collagen can be useful for distinguishing between diets based on different kinds of plants and also between terrestrial, marine, and occasionally freshwater resources (Schoeninger and DeNiro 1984).

4.2 DIETARY STABLE ISOTOPE ANALYSIS

Stable carbon isotope values are distinctly separated based on the two dominant photosynthetic pathways of land plants (C_3 or C_4 photosynthesis) (Lee-Thorp 2008; Smith and Epstein 1971). Plants that follow a C_3 photosynthetic pathway typically have $\delta^{13}C$ values around -26.5 ‰, whereas the $\delta^{13}C$ values of C_4 vegetation averages around -12.5 ‰ (Lee-Thorp, 2008). Most plants follow a C_3 photosynthetic pathway, as does much of the native vegetation in Central Chile, including those that were economically important (Planella et al. 2014; Planella and Tagle 2004; Planella 2005; Rossen et al. 2010). Most C_4 plants, on the other hand, are usually found in tropical and warmer climates, and generally include grasses and sedges. However, the C_4

group does also include some important cereal crops such as maize, sorghum and millet (Eriksson, 2013). The most economically important C_4 plant in this region was maize, the only true cereal in the Americas. Other edible C_4 plants that have been identified nearby, in southern Peru, include species from the *Graminae, Chenopodiaceae, Asteraceae* and *Amaranthaceae* families (Cadwallader et al. 2012). However, these have not been identified as a major source of dietary input in the Andean region lying within Chile and certainly none acquired the status of staples. Given the clear separation in $\delta^{13}C$ values of C_3 and C_4 plants, and maize being the only dominant C_4 contributor to human diets in Central Chile, stable carbon isotope analysis of human bone collagen is a particularly useful, and direct, method of detecting the introduction and intensification of this cereal into prehistoric diets.

Stable carbon isotope analysis of human tissues can assist in determining if a person relied on terrestrial or marine food systems. As well as the distinction between C_3 and C_4 plants, there is also a variation $\delta^{13}C$ values for marine plants and organisms, with higher values in marine resources compared to C_3 plants, but usually not quite as high as those observed in C_4 resources (Eriksson, 2013). The addition of stable nitrogen ($\delta^{15}N$) isotope analysis complements that of $\delta^{13}C$ analysis and is particularly helpful for distinguishing between mixed C_3-C_4 terrestrial diets from diets with a marine input. Stable nitrogen isotopes serve as a useful indicator of trophic level. Simply, the higher up the food chain an organism falls, the higher the $\delta^{15}N$ value in its tissues (Hedges and Reynard 2007; Schoeninger and DeNiro 1984). Marine, and indeed freshwater food chains, typically have many more levels than those of terrestrial food webs. Hence, a consumer towards the top of an aquatic food chain, such as humans, will have higher $\delta^{15}N$ values than a consumer at the top of a terrestrial food chain. However, it is important to consider that there are other factors which can also affect $\delta^{15}N$ values, such as the consumption of legumes, which are nitrogen-fixing plants and lower $\delta^{15}N$ values (Handley and Raven 1992), or arid environments and the use of manure to fertilise crops, both of which can elevate $\delta^{15}N$ values (Bogaard et al. 2013; Pate and Anson 2008; Santana-Sagredo et al. 2021; Szpak et al. 2012).

Samples of human bone from 256 individuals have been selected for stable isotope analysis (Table 3). Following the requirements of the Chilean heritage authority, *Consejo de Monumentos Nacionales de Chile,* samples could only be collected from already fragmentary material, without cutting or performing any further destruction to any of the material in order to obtain samples. Complying with these requirements, preference was given to selecting fragments of cortical bone from one of the long bones of the body (in particular, femur, tibia, humerus, ulna and radius). In instances where there was not a suitably small (approximately 1g) fragment of a long bone available, then a sample from a fragmentary rib would be collected. In instances where a fragment was unavailable from either a long bone or a rib, then a fragment of a cranial bone would be collected. A full list of each sample type is included in the supplementary material attached to Chapter 4 of this thesis. To provide some new baseline data for local food resources, seventeen faunal bone samples, found within the human osteological museum collections have also been collected for analysis. Eighteen modern plant samples of endemic species found growing wild within the study area were also collected.

				Adult (>18 years)			Subadult (5-18 years)
Setting	**Temporal[1]**	**Valley**	**Number of Individuals**	**Female**	**Male**	**Indet.[2]**	
Coast	*All*	*All*	*22*	*8*	*7*	*2*	*5*
	ECP	All	11	5	5	1	0
		Aconcagua Valley	3	0	2	1	0
		La Ligua Valley	8	5	3	0	0
	LIP	All	9	3	2	0	4
		Aconcagua Valley	0	0	0	0	0
		La Ligua Valley	9	3	2	0	4
	LP	All	2	0	0	1	1
		Aconcagua Valley	2	0	0	1	1
		La Ligua Valley	0	0	0	0	0
Inland	*All*	*All*	*234*	*71*	*71*	*49*	*43*
	ECP	All	51	13	17	18	3
		Aconcagua Valley	49	12	17	17	3
		La Ligua Valley	2	1	0	1	0
	LIP	All	54	14	17	8	15
		Aconcagua Valley	16	6	4	4	2
		La Ligua Valley	38	8	13	4	13
	LP	All	50	12	14	10	14
		Aconcagua Valley	49	11	14	10	14
		La Ligua Valley	1	1	0	0	0
	LIP/LP	All	79	32	23	13	11
		Aconcagua Valley	71	30	20	13	8
		La Ligua Valley	8	2	3	0	3
Total			**256**	**79**	**78**	**51**	**48**

Table 3: Samples obtained for stable carbon and nitrogen isotope analysis of bone collagen, presented by setting, temporal period and valley.

[1]*ECP = Early Ceramic Period, LIP = Late Intermediate Period, LP = Late Period, LIP/LP refers to samples attributed to the later agro-pastoral groups, either LIP or LP, but which could not be assigned to a specific category between the two.*

[2]*The adult age group has been further divided into categories of sex estimations Female, Male, and Indet. = indeterminate sex.*

4.3 OSTEOLOGICAL ANALYSIS

The preservation of the skeletal material included in this study is variable, with many being highly fragmentary (Figure 3), presenting some limitations to the osteological aspects of this research. In total, skeletal remains from 356 individuals from diverse chronological and geographical settings were deemed to be sufficiently preserved to yield some information relevant to this project. Primarily, osteological data were recorded for each individual to determine information useful for establishing basic biological profiles where possible. This basic biological data will complement the stable isotopic data and allow for additional analysis of results. All osteological assessment, observations and analyses were carried out by the author during field work seasons at the relevant museums housing the collections (Museo Histórico-Arqueológico de Quillota, the Museo Historia Natural de Valparaíso, the Museo Arqueológico de Los Andes, and the Museo La Ligua).



Figure 3: An example of the fragmentary nature and condition of preservation of many of the human remains from the Estadio de Quillota cemetery site, now housed at the Museo Historico Arqueologico de Quillota (source: author).

Where possible, sex estimations were made by visually assessing sexually dimorphic features of the pelvis and skull (Buikstra and Ubelaker 1994). In particular, the 5-point scoring systems (representing 'female' (F), 'probable female' (F?), 'indeterminate sex' (I), 'probable male' (M?) and 'male' (M)) recommended by Buikstra and Ubelaker (1994) (see also White and Folkens 2005) were utilised for the following morphological features of the skull: nuchal crest, mastoid process, supra-orbital margin, supra-orbital ridge, and mental eminence. Similarly the F, F?, I, M?, and M scoring system was also applied to assessing the following morphological features of the pelvis: sciatic notch, preauricular sulcus and subpubic concavity as described in Buikstra and Ubelaker (1994) and White and Folkens (2005). Additionally, morphological features of the mandible, including gonial angle, gonial eversion, and additional morphological features of the pelvis, including subpubic angle, pelvic inlet and obturator foramen were also assessed as 'male' or 'female' when available (see Bass 1995; Phenice 1969; White and Folkens 2005 for full descriptions).

In cases of conflicting results between morphological features of the pelvis and the skull, more weight was given to pelvic traits, which are more reliably sexually dimorphic (Rogers and Saunders 1994; White and Folkens 2005). Due to the poor preservation of the collections, only a handful of these features could usually be assessed for any individual, thus employing a 'best fit' (Powers 2012) approach to estimating sex based on the dimorphic features available for assessment. If only one trait was observable among fragmentary remains, the individual was assigned only to a category of 'probable female' (F?), 'indeterminate' (I) or 'probable male' (M?).

Age-at-death for subadults was primarily estimated based on dental eruption (Ubelaker 1989). If teeth were not present for assessment, stages of epiphyseal fusion were used as a secondary method (Scheuer and Black 2000). For adults, age-at-death was assessed based on the dental attrition method described by (Lovejoy 1985), developed on the Libben population of North America. Estimating age-at-death based on dental attrition was selected as the primary method due to the poor preservation of collections, meaning that other features that can be usefully employed in the assessment of age-at-death, such as the auricular

surface (Buckberry and Chamberlain 2002), the pubic symphysis (Brooks and Suchey 1990), or sternal rib ends (Yoder et al 2021). While it is recognised that there are some limitations with using dental attrition for estimating age-at-death, similar and additional limitations are encountered with all osteological methods of estimating age-at-death (Buckberry 2015; Falys et al. 2006; White and Folkens 2005). The dentition was consistently the better and most frequently preserved skeletal element for the greatest number of individuals among these Central Chilean collections. In order to maintain consistency in methodological approach, dental attrition was therefore employed as the primary age-at-death estimation technique. If no dentition was preserved, age-at-death estimations of 'adult' or 'subadult' were made using epiphyseal fusion (Buikstra and Ubelaker 1994; Scheuer and Black 2000).

Various pathological conditions in the skeleton can also be informative of dietary and nutritional status, perhaps none more so than dental pathologies. The dentition is, after all, the one part of the human skeleton that comes into direct contact with the foods consumed and the external environment. Teeth are generally well-preserved in archaeological settings and, unlike bones, do not remodel and obliterate their pathological lesions (Hillson 2001; Lukacs 1989). Dental health conditions can impair chewing efficiency and reduce appetite, impacting overall health and mortality rates.

A clear relationship has been established between increased dental pathologies and the adoption of agriculture (Cohen and Armelagos 2013; Steckel and Rose 2002; Turner 1979). Conditions such as carious lesions, ante-mortem tooth loss (AMTL), and periapical cavities can provide insight into subsistence strategies and dietary patterns, particularly when recorded at a population level (Hillson 2001; Roberts and Manchester 2005). These indicators of oral health are among the most frequently studied palaeopathological conditions as they have distinctive presentations (Larsen 1997).

		Dental Caries and AMTL				Periapical Cavities			
Setting and Diet	**Age**	**Total**	**F**	**M**	**I**	**Total**	**F**	**M**	**I**
Coast	*All*	*16*	*7*	*8*	*1*	*15*	*6*	*8*	*1*
Marine	All	9	3	6	0	8	2	6	0
	Adult (26-40)	1	1	0	0	1	1	0	0
	Mature (>40)	8	2	6	0	7	1	6	0
Marine C4	All	7	4	2	1	7	4	2	1
	Child (<15)	1	0	0	1	1	0	0	1
	Young Adult (16-25)	4	3	1	0	4	3	1	0
	Mature (>40)	2	1	1	0	2	1	1	0
Inland	*All*	*161*	*55*	*63*	*43*	*140*	*51*	*61*	*28*
Predominantly C3	All	21	5	9	7	17	5	9	3
	Child (<15)	2	0	0	2	0	0	0	0
	Adult (26-40)	4	1	3	0	4	1	3	0
	Mature (>40)	15	4	6	5	13	4	6	3
Mixed C3-C4	All	48	19	13	16	49	22	17	10
	Child (<15)	8	0	0	8	5	1	0	4
	Young Adult (16-25)	12	6	4	2	14	7	6	1
	Adult (26-40)	15	8	2	5	13	6	3	4
	Mature (>40)	13	5	7	1	17	8	8	1
Predominantly C4	All	76	26	39	11	63	18	33	12
	Child (<15)	11	0	0	11	10	0	0	10
	Young Adult (16-25)	33	16	16	1	29	14	14	1
	Adult (26-40)	20	5	14	1	16	4	11	1
	Mature (>40)	12	3	9	0	8	0	8	0
No dietary data	All	16	5	2	9	11	6	2	3
	Child (<15)	2	0	0	2	0	0	0	0
	Young Adult (16-25)	5	2	0	3	4	3	0	1
	Adult (26-40)	4	3	1	0	4	3	1	0
	Mature (>40)	5	0	1	4	3	0	1	2
Total		**177**	**62**	**71**	**44**	**155**	**57**	**69**	**29**

Table 4: Individuals examined for dental caries, AMTL, and periapical cavities presented by setting, dietary group (determined by stable isotope data presented in Chapters 2 and 4, and discussed further in Chapter 5) and age groups. The number of individuals has been further divided into categories of sex estimations: F = female, M = male, and Indet. = indeterminate sex.

The inclusion of fermentable carbohydrates as dietary staples generally accompanies the transition to agriculture in most parts of the world and was a catalyst to an increase in pathological conditions of the

dentition (Leverett 1982; Rowe 1975). Higher prevalences of dental caries, periapical cavities and AMTL have been observed with the introduction of maize agriculture in the New World (Larsen 1995) and in populations from Northern Chile (Alfonso et al. 2007; Kelley et al. 1991; Watson et al. 2010). Indicators of dental health, including dental caries, AMTL and periapical lesions have been recorded following Hillson (1996; 2001) for the permanent dentition of 177 individuals in the study area (Table 4). The prevalence of these conditions will be compared between groups, spatially as well as temporally, to examine trends relating to the introduction and intensification of maize agriculture, as determined by the isotopic data for diet.

4.4 RADIOCARBON DATING

Radiocarbon dating is a powerful dating method that can be used effectively in archaeological study to determine the age of objects that contain organic material (Libby 1949; Taylor and Bar-Yosef 2014). Carbon-14 (^{14}C) is a radioactive isotope of carbon that is present in the atmosphere. It is incorporated into the tissues of living organisms at a level representative of the atmospheric ^{14}C at that time. When the organism dies, this process stops and the ^{14}C begins to decay at a known rate. Measuring the residual ^{14}C in organic remains therefore can provide an estimate, within an error range, of how long since that organism died.

Statistical methods, such as Bayesian modelling and Kernel Density Estimates, can be used alongside radiocarbon dating to improve chronological resolution. Bayesian modelling incorporates known prior information (such as stratigraphy, for example), which can be used to constrain the probability distributions for a series of radiocarbon dates (Bayliss and Bronk Ramsey 2004; Bronk Ramsey 2015). This can be particularly helpful when interpreting groups of dates, or to model boundaries for overlapping date ranges. Bayesian modelling of prior assumptions can improve the chronological resolution for archaeological sites or particular events, such as the introduction of maize agriculture or the expansion of the Inka empire.

Kernel Density Estimation (KDE) is another statistical technique that can be applied to multiple radiocarbon dates to combine them into a single probability distribution (Bronk Ramsey 2017). KDE sums the probability

distributions of each radiocarbon date into a single continuous distribution and can be combined with Bayesian-modelled start and end boundaries, representing the combined overall density of the dates. Combining multiple dates into a single probability distribution can aide in visualisation and interpretation of collective data. This can be helpful when comparing different sets of dates with each other, and also in highlighting areas of higher probability densities within a distribution, identifying periods of higher activity within a related group of dates.

Much of the chronological development and temporal associations for the Aconcagua and La Ligua Valleys have so far largely been assigned using ceramic typo-chronologies and thermoluminescence (TL) dating, alongside some limited radiocarbon dates (Ávalos and Saunier 2011; Cornejo 2014; Sánchez et al. 2004). However, discrepancies have been noted in several TL dates in Chile, raising doubts about the reliability of TL in this region (Marsh et al. 2021; Pavlovic et al. 2012; Schiappacasse et al. 1991). As ceramic typo-chronologies have been anchored using TL dates, these discrepancies also undermine their reliability.

Very few AMS radiocarbon dates exist for the Aconcagua and La Ligua Valleys, and thus a robust chronological framework is lacking for this region despite its rich cultural heritage and the presence of two large and culturally significant cemeteries in these valleys: Estadio de Quillota in the Aconcagua Valley and Valle Hermoso in La Ligua Valley. The use of these cemeteries has been presumed to be relatively continuous from the beginning of the Early Ceramic Period (ca. 300 BC), through until the Late Period (ca. AD 1450) (Becker et al. 1995; Gajardo-Tobar and Silva 1970). This time span covers a number of important technological, economic and socio-political transitions. These include the transition to and intensification of maize agriculture, and also the assimilation of this southern frontier region into the Inka Empire. However, existing chronological data for these transitions is limited in this region.

As part of this thesis, funding was secured for new AMS radiocarbon dates of human bone collagen from the Aconcagua Valley cemetery site of Estadio de Quillota (*n*=17), the Los Andes area of the Upper Basin of the Aconcagua Valley (*n*=3), and the cemetery of Valle Hermoso in the La Ligua Valley (*n*=15). These new dates

are combined with existing conventional radiocarbon and thermoluminescence dates to improve temporal control of the material in this these. Bayesian modelling and Kernel Density Estimates (Bronk Ramsey 2017) are further employed to assist in providing greater chronological resolution of the shift and intensification of maize use and the arrival of Inka influence.

AMS radiocarbon dating was performed at the Oxford Radiocarbon Accelerator Unit (ORAU) and the W.M. Keck Carbon Cycle Accelerator Mass Spectrometer (KCCMS). Radiocarbon dates from ORAU are referenced with an 'OxA' lab code prefix when presented throughout this thesis and KCCMS dates with a 'UCIAMS' prefix. OxCal version 4.4 was used for all calibrations and Bayesian models (Bronk Ramsey 2024). All radiocarbon dates were calibrated using the SHCal20 Southern Hemisphere atmospheric curve (Hogg et al. 2020). All individual dates and modelled ranges were calibrated to 95.4% confidence, unless otherwise stated, and any modelled results are presented in italics.

5. Ethical Considerations

Bioarchaeological research involving human remains should always adhere to ethical principles and practices, such as consideration of the dignity of the deceased individuals, respect for their descendants and communities, as well as collaboration and transparency with relevant stakeholders (Scarre 2006; Tarlow 2006). Following such principles enables bioarchaeologists to approach the study of human remains in a manner that promotes understanding and appreciation across cultures (Lambert 2012; Roberts 2018).

The research, examination, sampling and analyses for this thesis were conducted with the cooperation and invitation of the four Central Chilean museums that house the bioanthropology collections used in this research; Museo Historico Arqueologico de Quillota, Museo Historia Natural de Valparaiso, Museo La Ligua and Museo de Los Andes. Local museums and heritage authorities were consulted throughout this research to obtain informed consent and address any concerns regarding the handling and analysis of human remains as well as agreement regarding the dissemination of results, research findings and subsequent publications.

Furthermore, approval for all sampling and analysis conducted in relation to this thesis was granted by the Chilean national heritage authority, the Consejo de Monumentos Nacionales de Chile, under permit number CMN-ARQUE N°516/2016, a regulatory oversight which ensures adherence to legal and ethical standards governing the study of archaeological human remains in Chile.

6. Bioarchaeological Research with Fragmentary Remains and Legacy Collections

This thesis endeavours to be a positive example in bioarchaeology. The combined methodology utilised in this thesis demonstrates the potential and importance of conducting research on heavily disturbed or fragmentary material with little preserved context. Through the application of techniques from bioarchaeology, as outlined above, this research is able to re-establish important contextual information for the prehistory of this region and takes the first steps in reconstructing the bioarchaeology for significant sites such as the cemetery at Estadio de Quillota, as well as other sites in the Aconcagua and La Ligua Valleys more broadly. As such, the findings to be presented here lay essential groundwork for the bioarchaeology of the Aconcagua and La Ligua, upon which further studies may be built.

This research also demonstrates the value in material that can be considered as 'legacy' or 'orphaned' collections (MacFarland and Vokes 2016; ; Voss 2012; Voss and Kane 2012). Orphaned or legacy collections are collections that have remained under-studied, under-curated, or poorly documented usually due to historical, logistical or resource-based limitations (Al Saad and Azaizeh 2023; Gregoricka 2023). Most of the collections of human skeletal remains used in this study have received little attention from other researchers, likely due to their fragmented nature combined with the lack of individual contextual data. Nonetheless, collections that have been overlooked in this way, can still provide a wealth of valuable data and even restore part of their lost narrative when approached with innovative methods and multi-proxy analyses.

The collections utilised for this thesis research, even though compromised in context and state of preservation, offer new insights into dietary transitions, agricultural intensification and health outcomes in the pre-Columbian populations of Central Chile. Integrating stable isotope analysis, analysis of dental pathologies, and radiocarbon dating, not only contributes to the larger picture of maize agriculture in the Americas, but also serves as an example of how bioarchaeological investigations can still yield substantial information from collections that might otherwise be dismissed or forgotten. This thesis thereby contributes to a growing body of literature in demonstrating the value of working with legacy and orphaned collections, as both a means of expanding existing datasets, as well as a methodological framework for extracting meaningful new information from fragmentary or forgotten remains (Al Saad and Azaizeh 2023; Gregoricka 2023; St. Amand et al. 2020; Voss 2012).

7. Contribution

This thesis makes a substantial contribution to the bioarchaeology of Central Chile, particularly the Aconcagua and La Ligua Valleys, which have been understudied relative other regions in the South and South Central Andes. A multi-proxy approach is taken, combining osteological analysis and dental pathology data, alongside stable isotope analysis and radiocarbon dating, in order to address multiple questions relevant to the prehistory of the region. This is the first large-scale and comprehensive study of dietary stable isotopes and dental pathology data from human remains in these valleys. The findings presented within this thesis contribute new information and dietary practices from the ECP to the LP in this region, with particular reference to the adoption and intensification of maize agriculture. Some of the key contributions of this thesis are as follows:

1. Demonstrating the value of legacy and orphaned collections

The collections included in this research are mostly fragmentary, poorly preserved, and/or lacking contextual information. This research demonstrates that collections still hold significant value, especially with the ongoing advancement of techniques from bone chemistry and biology that can be applied to bioarchaeological collections.

2. Reconstructing dietary patterns over time.

The dietary stable isotope data presented in this thesis provide new insights into the timing and adoption and intensification of maize agriculture in Central Chile. It also expands the regional understanding of maize agriculture in the Southern Andes and demonstrates that the transition to intensive maize agriculture was not a sudden or uniform event, but rather a gradual process over several centuries. The results support a gradual adoption of maize from the ECP onward, with consumption of this staple crop peaking during the LIP and LP. Maize was likely introduced around AD 450–600, then intensifying during the LIP, possibly associated with new socio-political influences in the region. Furthermore, evidence of differential access to maize-based foods based on sex also suggest a broader socio-cultural or behavioural significance for maize beyond its role as a dietary staple.

3. Identifying social and cultural roles of maize

This research identifies differences in maize access between sexes. The differences in maize consumption between adult males and females implies an unequal access to the resource tied to social identity or cultural roles and in turn suggesting a greater significance for maize beyond its economic value.

4. Examining oral health impacts associated with agricultural transitions

The thesis contributes to the understanding of how dietary and agricultural transitions can affect oral health. In the Aconcagua and La Ligua Valleys, increases in dental caries and AMTL correlate with the dietary stable isotope data indicating greater maize consumption. Furthermore, females were disproportionately affected by caries, even when consuming less maize than males, pointing to both dietary and biological factors affecting oral health. Moreover, this particular finding supports an argument for more gender-aware interpretations of diet and health in the archaeological record.

5. Refining regional chronology

Thirty-five new AMS radiocarbon dates for the Aconcagua and La Ligua valleys are presented in this thesis. These new dates refine the timeline of maize adoption and the transition to more intensive maize farming. The radiocarbon data, coupled with Bayesian modelling, also challenge the conventional timeline for Inka expansion, suggesting an earlier presence (possibly late 14th century).

Finally, this thesis not only contributes to the prehistory of Central Chile, it also informs broader discussion in bioarchaeology, particularly around the use of fragmentary legacy collections to reconstruct valuable information, ongoing discussions of the transition to agriculture and its impact on human health, as well as developing insights into gendered and social aspects of diet and agricultural transitions in prehistory.

8. Thesis Structure

This thesis is presented in the following format:

Chapter 1:

Introduction

Outlines the main aims, hypotheses and background relevant to this research.

Chapter 2:

Paper 1 - *Prehispanic diet in the Valparaíso region of Central Chile: Evidence from stable carbon and nitrogen isotope analysis of human bone collagen from the collections of the Museo de Historia Natural de Valparaíso*

The stable isotope analyses in this thesis are presented across two chapters (Chapter 2 and 4). This chapter, the first of the stable isotope articles, presents stable carbon and nitrogen isotope data specifically for the samples from the collections of the Museo de Historia Natural de Valparaíso, providing new information on prehistoric dietary practices in the Valparaíso region of Central Chile from the Early Ceramic, the Late Intermediate and the Late Period.

As this article has already been published in Spanish language (Swift et al. 2017), an English translation is presented in Chapter 2, and the original article included as an Appendix.

Chapter 3:

Paper 2 - *A Radiocarbon Chronology for Estadio de Quillota in the Aconcagua Valley, Central Chile, with reference to the adoption of intensive maize agriculture and revisiting the timing of Inka influence on the southern frontier.*

This chapter (Swift et al. 2022) utilises radiocarbon dating to refine the chronology of the Aconcagua Valley, establishing an initial chronology for Estadio de Quillota, the largest cemetery in the Aconcagua. The suite of new radiocarbon dates, along with Bayesian modelling, also investigates the timing of two significant events in the region: the introduction of maize to the diet and the arrival of Inka Influence, which is coeval with the transition to the Late Period in Central Chilean archaeology.

Chapter 4:

Paper 3 - *The Frontier of Maize Agriculture: Stable Isotope Evidence of Pre-Columbian Dietary Shifts in the Aconcagua and La Ligua Valleys of Central Chile*

Chapter 4 builds upon both the first stable isotope article (Chapter 2) and the radiocarbon article (Chapter 3). Stable carbon and nitrogen isotope analyses are presented from 242 individuals from the Aconcagua and La Ligua Valleys of Central Chile, alongisde an additional 18 radiocarbon dates. The stable isotope analyses focus on the transition to maize agriculture. Dietary patterns are reconstructed across geographic, cultural, and temporal settings from the Early Ceramic Period to the Late Period.

Chapter 5:

Paper 4 - *Maize and Dental Health: The Impact of Agricultural Transition in the Pre-Columbian Aconcagua and La Ligua Valleys of Central Chile*

This chapter examines dental palaeopathologies, specifically dental caries, ante-mortem tooth loss (AMTL) and periapical cavities, in the Aconcagua and La Ligua Valley populations to understand the impact of the transition to maize agriculture on oral health. The relationship between diet, particularly maize consumption, and dental lesions is explored. Variability in oral health between the sexes before and after the adoption of maize as a dietary staple is also considered in the light of other potential pathogenic factors related to differences between the biological sexes and major transitions subsistence strategies.

Chapter 6:

Conclusion

The conclusion chapter provides a summary of key findings presented in the thesis, as well as a brief discussion of limitations and directions for future research.

CHAPTER 2: PREHISTORIC DIET IN THE VALPARAÍSO REGION OF CENTRAL CHILE: EVIDENCE FROM STABLE CARBON AND NITROGEN ISOTOPE ANALYSIS OF HUMAN BONE COLLAGEN FROM THE COLLECTIONS OF THE MUSEO DE HISTORIA NATURAL DE VALPARAÍSO

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Keywords: Paleodiet, human remains, bones, Bato, Llolleo, Aconcagua, Inka.

Abstract

The objective of this research was to provide new information regarding prehistoric dietary practices in the Valparaíso region, using evidence from stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopic analyses of human bone collagen. Samples were obtained from human skeletal remains of 24 individuals previously recovered from various archaeological sites within the region. The results demonstrated variability in dietary practices over different temporal (Early Ceramic through to Late) and geographic settings (coastal vs inland), particularly regarding the consumption of C_4 (maize) or marine resources. A wide range of $\delta^{13}C$ values from the material studied particularly points towards an increasing inclusion of maize in the diet over time. The new isotopic data also suggest that the local, coastal diet included a mixture of terrestrial foods supplemented by marine resources, especially those of lower trophic levels such as molluscs or seaweeds,

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whereas low $\delta^{15}N$ values for inland groups, infer a terrestrial diet that may have either been low in animal proteins or included regular consumption of nitrogen-fixing legumes.

1. Introduction

Dietary practices in pre-Columbian Central Chile have previously been described as a defining feature of the region's different cultural groups (Falabella et al., 2007). Much of the existing paleodietary research in Central Chile is based on sites from the Santiago and Rancagua regions (Falabella et al., 2007; Falabella et al., 2008; Planella et al., 2014; Sanhueza and Falabella, 2010; Tykot et al., 2009). From the Early Ceramic Period onwards, a variety of dietary and subsistence practices have been observed, including the contemporaneous existence of groups of hunter-gatherers and incipient agriculturalists, the introduction of domesticated maize and the subsequent intensification of agricultural practices.

Previous inferences about diet within the Valparaíso region of Central Chile have relied upon archaeobotanical and zooarchaeological evidence (Belmar et al., 2013; Carmona et al., 2001), patterns of dental palaeopathology (Arriagada and Oyanedel, 2014; Henríquez, 2006) and the palaeoenvironmental potential of the region (Ávalos and Saunier, 2011). Stable isotopic analysis of human skeletons can provide evidence of diet and subsistence strategies in the past by distinguishing between different resources that were consumed, such as marine versus terrestrial foods, and C_4 (maize) versus C_3 (quinoa, potatoes, fruits) plants. This research presents the results of stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopic analyses of human bone collagen from the bioanthropological collections of the Museo de Historia Natural de Valparaíso (MHNV), with the aim of providing new information regarding prehistoric dietary practices in the Valparaíso region of Central Chile.

2. Background

The Valparaíso Region of Central Chile extends from 31°55'S to 33°38'S and marks the transition from the deserts of the north to the more fertile landscape of Central Chile. The region is crossed by various river systems, and includes the large fluvial Aconcagua basin. The terrain is varied from west to east including distinct geographical zones from the Pacific coast, the coastal cordillera, the inland valley and the Andean cordillera (Figure 1). The dominant native vegetation in the inhabitable zones consists of sclerophyllous shrub and forest (Bambach et al., 2013; Moreira-Muñoz, 2011).



Figure 1: *Map of the study area showing the location of archaeological sites for the material included in this study.*

The area is subject to a Mediterranean climate with dry summers and wet winters. The current climatic conditions have remained much the same for the last 3,000 years with seasonal and inter-annual variations in rainfall influenced by El Niño Southern Oscillation fluctuations (Jenny et al., 2002; Villagrán and Varela, 1990; Villa-Martínez et al., 2003).

People began to inhabit the broader region of Central Chile during the late Pleistocene and various temporal periods and cultural traditions have been described for the subsequent human prehistory of the region (Falabella et al., 2016; Núñez et al., 2016; Uribe and Sánchez, 2016). The human skeletal material subject of this research relates to late Holocene populations from the Early Ceramic Period through until the Late Period (c. 300 BC – 1536 AD).

2.1 EARLY CERAMIC PERIOD (C. 300 BC – 1000/1200 AD)

The appearance of ceramics in the archaeological record denote the beginning of the Early Ceramic Period (ECP), although, the introduction of this new technology did not necessarily signal a simultaneous change in the lifeways of hunter-gatherers. In fact, this period is characterised by small, heterogeneous groups of people coexisting in the same region, while maintaining different subsistence practices, material culture, funerary practices and settlement patterns. Some early ceramic groups maintained a hunter-gatherer lifestyle, with little change in subsistence strategy throughout much of this period, while other groups transitioned to incipient agriculture with the presence of cultigens, such as quinoa (*Chenopodium quinoa*) and maize (*Zea mays*) inferring the beginning of small scale arable fields (Ávalos, 2005; Ávalos and Saunier, 2011; Falabella et al., 2016; Planella and Tagle, 2004).

A number of cultural complexes have been proposed within the Early Ceramic Period, some of which were diachronic and some synchronic. The better defined of these include the Initial Ceramic Communities (c. 300 BC - 200 AD), the Bato (c. 200 - 1000 AD) and the Llolleo (c. 200 - 1200 AD) (Falabella and Stehberg, 1989; Falabella et al., 2015; Sanhueza Riquelme, 2016). The Initial Ceramic Communities (ICC) were primarily dependent upon wild (C_3) plant resources, although the presence of quinoa has also been recorded at some ICC sites (Quiroz and Belmar, 2004; Sanhueza and Falabella, 1999).

Sites affiliated with the Bato cultural complex are primarily located to the west of the coastal Cordillera, with higher concentrations in the more northern part of the Central Chilean coast, particularly around the mouth of the Aconcagua River (Ávalos and Saunier, 2011). However, Bato contexts have also been recorded at some

inland sites in the region as well (Ávalos, 2007; Hermosilla, 1994). The Bato largely practised a hunter-gatherer lifestyle with some degree of territorial mobility and a reliance on near-shore, low-trophic-level marine foods, wild camelids and wild plant resources (Ávalos and Saunier, 2011; Carmona et al., 2001; Rivas and Gonzalez, 2008). However, the presence of grindstones and archaeobotanical remains of quinoa and maize at some sites, particularly the inland sites, also demonstrates the Bato's incipient use of, or access to, some early domesticates (Ávalos, 2005; Planella and Tagle, 2004).

The Llolleo co-existed alongside the Bato, although they are regarded as more sedentary and with a greater focus on cultigens. Small, self-sufficient groups with a collective Llolleo identity established dispersed settlements throughout the middle and upper sequence of the Aconcagua Valley, the Santiago Basin, the Rancagua Basin, and also a few coastal sites, mainly surrounding the mouth of the Maipo River (Falabella et al., 2016). A mixture of both wild and cultivated plants, alongside guanaco (*Lama guanicoe*) bones have been recorded at Llolleo sites in the Maipo-Mapocho basin (Planella and Tagle, 2004). Limited hunting equipment has been indetified in Llolleo contexts, with fewer projectile points than Bato sites, suggesting hunting large game was of less importance to the Llolleo than their Bato counterparts (Falabella et al., 2016). Cultigens that have been identified in Llolleo contexts include maize, quinoa, beans (*Phaseolus sp.*), squash (*Curcurbita sp.*), and gourds (*Lagenaria sp.*) (Planella et al., 2014; Planella and Tagle, 2004; Sanhueza et al., 2003).

2.2 LATE INTERMEDIATE PERIOD (C. 1000/1200 AD – 1450 AD)

The transition to the Late Intermediate Period (LIP) brought about considerable cultural and technological change, with the Aconcagua recognised as the dominant cultural complex in Central Chile during this period. Settlements were generally located along the fluvial terraces of river valleys and comprised a few residential units. Fields for cultivating crops were situated adjacent to habitation areas, and spaces were also designated for processing food and the production of lithics and pottery. While the Aconcagua preferentially inhabited the inland valleys, some Late Intermediate Period sites have also been recorded in coastal settings, such as Las Brisas 10-14 (Westfall, 1999).

The development of more intensified agriculture appeared among some Central Chilean groups around c. 1000 AD, but for others did not take place until around c. 1200 AD (Falabella et al., 2016). Increased dependence upon maize is demonstrated by a ubiquity of the resource at sites in the region from this period, an increase in the size of the kernels and a greater diversity of maize varieties (Belmar and Quiroz, 2003b; Planella et al. 2014 in Falabella et al., 2016). An increase in the size and variety of beans, and the grain size of quinoa provide further evidence for the intensification of agriculture during this period (Planella et al., 2015). There is also indication of an increased reliance on guanaco meat, and suggestion that camelids may have been partially domesticated, being fed on maize stover to encourage them to stay close to settlements (Becker, 1994; Sanhueza and Falabella, 2010; Tykot et al., 2009).

2.3 LATE PERIOD (C. 1450 AD – 1536 AD)

An Inka presence was established in Central Chile by the 15th century. Conservatively, it is accepted by around c. 1450 AD (Uribe and Sánchez, 2016), although there are some thermoluminesence dates from ceramics that suggest a possible earlier presence, prior to 1400 AD (Sánchez, 2003). The Inka road network has been recorded running longitudinally through Central Chile towards the south and passing through the Andes towards Mendoza in Argentina to the east. Imperial structures used for ceremonial, defensive and administrative purposes, were established at strategic points along the river valleys and longitudinal roads (Coros and Coros, 1999), integrating the area into the southern frontier of their empire.

Existing local cultures, such as the Aconcagua and Diaguita, persisted into the Late Period (LP), but were partially acculturated, exhibiting signs of Inka influence in their material culture. A more defined hierarchy was implemented with social units headed by local *caciques*, and previously dispersed communities were organized into small settlements. Various forms of production were increased, including mining, further intensification of maize agriculture and domestication of camelids (Uribe and Sánchez, 2016).

2.4 STABLE ISOTOPE ANALYSIS

Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analyses have been increasingly applied in archaeological contexts to reconstruct diet and infer prehistoric subsistence strategies. Differences in carbon and nitrogen isotope ratios can be useful for distinguishing between diets reliant upon different types of plant resources, as well as between marine, terrestrial and sometimes freshwater ecosystems (Schoeninger and DeNiro, 1984). Stable carbon isotope ratios are calculated relative to an international standard, the PeeDee Belemnite (PDB) carbonate, which is rich in ^{13}C, meaning the $\delta^{13}C$ values measured from most plants and animals are negative when reported relative to the standard. Stable nitrogen isotope ratios are measured and reported relative to atmospheric nitrogen (AIR).

The stable isotopic values from bone collagen represent a longer-term average of diet, approximately over the last decade of life. However, the bone turnover rate can vary somewhat depending on factors such as age, nutritional status, and the particular bone that has been sampled for analysis (Tieszen et al., 1983; Hedges et al., 2007). Furthermore, the $\delta^{13}C$ in bone collagen is biased towards the protein portion of the diet (Ambrose and Norr, 1993; Tieszen and Fagre, 1993), and for $\delta^{15}N$ represents only the protein component of the diet, meaning the dietary contribution from the lipid and carbohydrate portions of food will be underrepresented in bone collagen data.

Stable carbon isotopes can distinguish between some types of terrestrial resources based on different photosynthetic pathways used by plants (such as C_3 or C_4). In a Central Chilean setting, stable carbon isotopic analysis can be particularly useful for detecting the introduction and intensification of maize (a C_4 resource) in prehistoric human diets. Vegetation in temperate zones generally follows a C_3 photosynthetic pathway, as does much of the native vegetation from Central Chile. Certain important cultigens and cereals, including maize, follow the C_4 photosynthetic pathway. Stable carbon isotope values for C_3 vegetation generally average around -26.5 ‰, whereas C_4 plants have values around -12.5 ‰ (Smith and Epstein, 1971). Modern plants require a correction of c. +1.5 ‰ when compared with archaeological material due to the Suess Effect;

a depletion in atmospheric carbon isotope ratios as a result of admixture with industrial carbon dioxide produced from the combustion of fossil fuels (Keeling, 1979).

There is an offset, due to metabolic processes, between the isotopic values of plants and the body tissues of the animals that consume them. Mammals have a shift of about +5 ‰ from the $\delta^{13}C$ values of the resource to the $\delta^{13}C$ values observed in bone collagen of the consumer ($\Delta^{13}C_{diet\text{-}collagen}$) (Ambrose and Norr, 1993; Tieszen and Fagre, 1993). This includes a trophic level shift of c. +1 ‰ for carbon isotopes, which also occurs for each subsequent step in the food chain (Bocherens and Drucker, 2003).

Previously published isotopic data for various species of plants in Central Chile (see Table 1) can provide an indication of the $\delta^{13}C$ endpoints that might be expected for consumers of C_3 or C_4 plants in this region. Based on the average value of both wild and cultivated C_3 plants from Central Chile at 26.6‰, herbivores consuming an exclusively C_3 diet would theoretically have $\delta^{13}C$ bone collagen values around -20.1 ‰ (when accounting for the +5 ‰ $\Delta^{13}C_{diet\text{-}collagen}$ shift, and adding an additional +1.5 ‰ to account for the Suess Effect). If humans had a diet featuring C_3 grazing herbivores, such as *Lama guanicoe*, their estimated $\delta^{13}C$ endpoint would be around -19.1 ‰. An estimated $\delta^{13}C$ bone collagen endpoint for a pure C_4 diet would be around -4.7‰. However, it is unlikely, even in heavily maize-dependent communities, that people would derive 100% of their dietary protein from C_4 resources. Various studies from Central and South America have reported average $\delta^{13}C$ values around -12.1 to -9.2 ‰ for maize agriculturalists (Finucane et al., 2006; Williams, 2005; Reed, 1994; Williams et al., 2017).

Resource	Context	*n*	Mean $d^{13}C \pm 1$ SD (‰)	Min. – Max.
Marine Algae	Modern	2	-15.7 ± 2.3	-17.3 – -14.0
C_3 Wild Vegetation	Modern	14	-26.6 ± 2.9	-30.5 – -21.0
C_3 Cultigens	Modern	6	-26.6 ±1.6	-29.3 – -24.7
C_4 Cultigen	Modern	1	-11.2	

Table 1: Summarised stable carbon isotope values for modern samples of Central Chilean flora, adapted from Falabella et al. (2007).

Humans consuming a diet with a mixture of terrestrial resources will have $\delta^{13}C$ values intermediate to the C_3 and C_4 dietary endpoints. However, the stable carbon isotope values of marine plants also lie between these endpoints, thus potentially overlapping with values expected of a mixed terrestrial diet. This can complicate efforts to distinguish a marine-based diet from a terrestrial C_3-C_4 diet when interpreting $\delta^{13}C$ results alone.

Stable nitrogen isotopes provide information about trophic level, with an increase of about 3-5 ‰ for each step up the food chain (Schoeninger and DeNiro, 1984). As there are many more trophic levels in the marine food chain, compared to terrestrial food chains, consumers of marine resources can be distinguished by higher $\delta^{15}N$ values. For example, prehistoric European farmers with diets consisting of terrestrial plants and animals have $\delta^{15}N$ bone collagen values around 8-11 ‰, a mixed diet of terrestrial and marine protein will result in intermediate $\delta^{15}N$ values around 11-15 ‰, and marine hunters consuming higher trophic level resources will have even higher $\delta^{15}N$ values, often around 15-20 ‰ (Schoeninger and DeNiro, 1983; Schulting, In press). Populations from coastal northern Chile known to be heavily reliant on high trophic level marine foods have been reported with $\delta^{15}N$ as high as 17.3 to 26.7 ‰ (Roberts et al. 2013).

There are other factors, apart from trophic level shift, that can also elevate $\delta^{15}N$ in food resources, such as aridity (Pate and Anson, 2008) and manuring crops (Bogaard et al., 2007; Szpak et al., 2012; Bogaard et al., 2013; Fraser et al., 2011). Conversely, nitrogen-fixing plants, which includes most legumes, have depleted $\delta^{15}N$ compared to non-leguminous plants due to their ability to fix nitrogen directly from the atmosphere (Handley and Raven, 1992). Therefore, humans consuming a diet featuring legumes would also have relatively depleted $d^{15}N$. Indeed, consumption of legumes has been suggested as explanation for lowered human $\delta^{15}N$ bone collagen values from middle Neolithic sites in France (Schulting and Hamilton, 2012).

Baseline isotopic data are available for various archaeological and modern faunal resources from Central Chile (Falabella et al., 2007) and provide a useful background for this study (see Table 2). These samples

were obtained from the broader Central Chilean region, incorporating some parts of the study area for this research.

Faunal Resource	Context	Material	*n*	Mean $\delta^{13}C$ ± 1SD (‰)	Min. – Max.	Mean $\delta^{15}N$ (‰)	Min. – Max.
Terrestrial Herbivores	Archaeological	Bone	6	-19.5 ± 0.6	-20.2 – -18.6	5.0 ± 0.9	4.0 – 6.4
Lacustrine (Inland)	Archaeological	Bone	1	-16.0		2.1	
Lacustrine (Coastal)	Archaeological	Bone	2	-22.9 ± 0.8	-23.4 – -22.3	7.1 ± 2.6	5.2 – 8.9
Marine Mammal	Archaeological	Bone	1	-11.7		20.2	
Marine Fish	Archaeological	Bone	1	-14.9		12.7	
Marine Fish	Modern	Bone	4	-13.5 ± 1.7	-15.5 – -11.4	17.7 ± 1.1	16.0 – 18.5
Marine Molluscs	Modern	Flesh	4	-15.3 ± 1.7	-17.2 – -13.2	16.0 ± 1.5	14.2 – 17.6

Table 2: Summarised stable carbon and nitrogen isotope values for Central Chilean fauna, adapted from Falabella et al. (2007).

Previous isotopic research from Central Chilean sites further to the south, around the Maipo, Mapocho and Cachapoal Rivers in the Santiago and Rancagua regions present data from human bone collagen for about 82 individuals (Falabella et al., 2007; Falabella et al., 2008; Sanhueza and Falabella, 2010; Tykot et al., 2009). These include populations from coastal sites, inland valleys and the Andean cordillera, and encompass temporal and cultural periods from the Archaic through to the Late Period.

The limited evidence for Archaic diets from the region indicates that hunter-gatherers from this period were dependent upon a C_3 ecosystem (Sanhueza and Falabella, 2010). A similar trend was observed into the Initial Ceramic Communities of the Early Ceramic Period. Isotopic evidence from the Early Ceramic Period after about 200 AD in Central Chile demonstrates the contemporaneous practice of at least two different terrestrially-based subsistence strategies at inland sites, often linked to the contemporaneous Bato and Llolleo cultural complexes described for this region. Isotopic analyses from sites surrounding the Maipo, Mapocho and Cachapoal Rivers, demonstrated that the Llolleo had some input from C_4 cultigens, whereas the Bato revealed more variable results suggesting a moderate reliance on marine resources for some, while others consumed a C_3 terrestrial diet (Falabella et al., 2007; Sanhueza and Falabella, 2010).

Previous isotopic results from the Late Intermediate Period found significant enrichment of $\delta^{13}C$ in human bone collagen, indicating the dominant cultigen of choice was maize (Falabella et al., 2007). Maize continued to feature in the diet of Late Period groups, although it was reduced in proportion (more negative $\delta^{13}C$ values) and mixed with a greater input of C_3 resources when compared to the Late Intermediate Period (Falabella et al., 2007).

3. Materials and Methods

3.1 SAMPLES

Human bone samples were selected from 24 individuals held in the bioanthropology collection of the Museo de Historia Natural de Valparaíso (Table 3). All skeletal remains were highly fragmentary. To minimise further damage to the collection, samples for stable isotopic analysis were only selected from already fragmented material. The sampled material derives from various sites within region V (Valapraíso region) of Central Chile. The sites include the Early Ceramic (*n* = 19), the Late Intermediate (*n* = 3) and Late Periods (*n* = 2) and are from both coastal (*n* = 12) and inland (*n* = 12) settings (see Figure 1). Coastal sites are defined as those located along the coastal plain, to the west of the coastal cordillera, whereas inland sites are those located within the coastal cordillera or further into the inland valley. There is a distance of approximately 17 km from the coast to the nearest inland site included in this study (Villa Alemana). The contextual information available for the human skeletal assemblages is variable, and in some cases limited only to the museum storage label.

Sample	Site	Individual*	Period (Culture)	Setting	Sex	Age	Sample
16039	Las Brisas 3	1	ECP (Bato)	Coastal	uk	Subadult (~11.5 years)	Radius
16040	Las Brisas 10-14	1	LIP (Aconcagua)	Coastal	F?	Adult (35-40)	Femur
16041	Las Brisas 10-14	2	LIP (Aconcagua)	Coastal	F	Adult (45-55)	Rib
16042	Las Brisas 10-14	3	LIP (Aconcagua)	Coastal	F	Adult (45-55)	Tibia
16043	Concon, Camino Internacional+	1	ECP (Bato)	Coastal	M	Adult (45-55)	Fibula

16044	Concon, Camino Internacional[+]	"individuo removido"	ECP (Bato)	Coastal	uk	Adult (40-50)	Cranium
16045	Concon, Camino Internacional[+]	2	ECP (Bato)	Coastal	F?	Adult (45-55)	Rib
16046	Papudo	nd	ECP[#]	Coastal	F	Adult (16-20)	Femur
16047	Papudo	nd	ECP[#]	Coastal	F?	Adult	Cranium
16048	Papudo	nd	ECP[#]	Coastal	F	Adult	Cranium
16049	Calle Ricardo, Santa Cruz	Enterratorio 2653	ECP (Llolleo)[#]	Inland	M	Adult	Fibula
16050	Calle Ricardo, Santa Cruz	Enterratorio 2654	ECP (Llolleo)[#]	Inland	uk	Adult (45-55)	Femur
16051	Calle Ricardo, Santa Cruz	Enterratorio 2655	ECP (Llolleo)[#]	Inland	uk	Adult	Femur
16052	Calle Ricardo, Santa Cruz	Enteratorio 2655	ECP (Llolleo)[#]	Inland	M?	Adult	Cranium
16053	Calle Ricardo, Santa Cruz	Enteratorio 2656	ECP (Llolleo)[#]	Inland	M?	Adult	Cranium
16054	Calle Ricardo, Santa Cruz	Enteratorio 2657	ECP (Llolleo)[#]	Inland	uk	Adult	Femur
16055	Calle Ricardo, Santa Cruz	Enteratorio 2658	ECP (Llolleo)[#]	Inland	uk	Adult	Femur
16056	S-Bato 1	"Disturbado"	ECP (Bato)	Coastal	uk	Adult	Femur
16057	S-Bato 1	1	ECP (Bato)	Coastal	M?	Adult (35-50)	Rib
16058	Villa Alemana	1	LP (Aconcagua-Inka)	Inland	uk	Subadult (16.5-19.5)	Tibia
16059	Villa Alemana	2	LP (Aconcagua-Inka)	Inland	uk	Adult	Cranium
16060	Las Chilcas	“Hallazgo 10”	ECP (Bato)	Inland	M	Adult (45-55)	Cranium
16061	Pocochay	1	ECP (Llolleo)[#]	Inland	M	Adult (45-55)	Radius
16062	Pocochay	2	ECP (Llolleo)[#]	Inland	M?	Adult (24-30)	Cranium

*Table 3: Details of the human bone samples from the bioanthropology collection of the Museo de Historia Natural de Valparaíso. *The individual numbers/names recorded here are as per the museum labels associated with the remains. [#]Cultural and temporal attributions have been made for these samples based on museum labels only. [+]These samples may relate to two sites Concon 11 and Camino Internacional, located 150m apart. However, the remains are now stored together with no indication of which came from Concon 11 and which from Camino Internacional.*

3.2 METHODS

Where possible, sex was determined by morphological assessment of pelvic and skull fragments (Buikstra and Ubelaker, 1994). Age was estimated based on dental eruption for subadults (AlQahtani et al., 2010) and dental attrition for adults (Lovejoy, 1985).

Stable carbon and nitrogen isotopic analysis were carried out at the Research Laboratory for Archaeology and the History of Art at the University of Oxford. Collagen was extracted from the bone samples using a

protocol modified from Longin (1971). Bone fragments were cleaned by shot blasting with aluminium oxide. Sub-samples were crushed and demineralised in 0.5 M HCl at 5°C for several days. The HCl solution was changed periodically until the samples ceased to evolve observable CO_2 in reaction to the acid. The demineralized samples were placed into sealed tubes of pH 3 H_2O and gelatinized at 70°C for 48 hours. The supernatant was filtered to remove insoluble residue using 45-90 µm Ezee-filters™ and then freeze-dried for approximately 48 hours.

Collagen was analysed using a Sercon 20/22 Isotope Ratio Mass Spectrometer in continuous flow mode. All samples were analysed in duplicate to ensure reproducibility, with a precision greater than ± 0.2 ‰. Internal alanine standards of known value were included throughout runs to allow for drift correction. Matrix-matched in-house standards of cow and seal collagen were also included for two-point calibration of the results (Coplen et al., 2006). The averaged isotopic values are reported in unit per mil (‰) relative to international standards for $\delta^{13}C$ (VPDB) and $\delta^{15}N$ (AIR).

IBM SPSS Statistics for Macintosh, version 22.0, was used for all statistical analyses. Data were tested for normality using Shapiro-Wilk tests, which determined the subsequent use of parametric (student's *t* test) or nonparametric (Mann-Whitney *U*) tests when comparing two groups. Two-tailed tests were employed, with $\alpha = 0.05$.

All but one of the 24 samples met accepted collagen quality criteria with yields > 1 % and C:N between 2.9 and 3.6 (Table 4) (DeNiro, 1985; van Klinken, 1999). One sample from Villa Alemana (16058) had an unacceptably high C:N at 3.86, and has been excluded from further analysis.

4. Results and Discussion

Results are shown in table 4 and figure 2, and summarized by geographic and temporal setting, alongside comparative data from the Santiago and Rancagua regions in Table 5. There are significant differences for both the $d^{13}C$ and $d^{15}N$ values for the coastal sites compared to the inland sites ($p = 0.006$ for $\delta^{13}C$, $p = 0.001$

for $\delta^{15}N$, Mann-Whitney *U* tests). However, the range of $\delta^{15}N$ values from the coastal sites of Central Chile (5.4 ‰ to 14.8 ‰, mean 10.5 ± 1.9 ‰) is much less elevated than the $\delta^{15}N$ values of the highly marine resource dependent populations from the hyper-arid region of northern Chile (see Figure 3) (Petruzzelli et al., 2012; Roberts et al., 2013; Santana-Sagredo et al., 2016; Santana-Sagredo et al., 2015). The $\delta^{15}N$ and δ $\delta^{13}C$ values from this study nonetheless suggest that the local, coastal diet included a mixture of terrestrial resources supplemented by marine resources, particularly those of lower trophic levels such as molluscs or seaweeds. These results are consistent with the presence of archaeological shell middens recorded along the coast (Carmona et al., 2001; Seelenfreund and Westfall, 2000). Similar differences between coastal and inland groups were observed in previous isotopic research from Central Chile and, for the Early Ceramic Period, were interpreted as evidence of inhabitation in defined ecological zones, rather than a model of regular migration between the coast and interior (Falabella et al., 2007).

Sample	Site	Temporal Period	Setting	Sex	Age	$\delta^{13}C$ (‰V PDB)	$\delta^{15}N$ (‰ AIR)	% Yield	C:N	%N	%C
16039	Las Brisas 3	ECP (Bato)	Coastal	uk	Subadult (~11.5 years)	-17.9	11.7	7.6	3.25	15.7	43.7
16040	Las Brisas 10-14	LIP (Aconcagua)	Coastal	F?	Adult (35-40)	-13.5	5.4	7.6	3.23	13.3	36.8
16041	Las Brisas 10-14	LIP (Aconcagua)	Coastal	F	Adult (45-55)	-13.1	10.0	17.5	3.24	15.4	42.7
16042	Las Brisas 10-14	LIP (Aconcagua)	Coastal	F	Adult (45-55)	-13.5	9.4	4.5	3.31	12.6	35.7
16043	Concon, Camino Internacional	ECP (Bato)	Coastal	M	Adult (45-55)	-15.8	10.0	8.7	3.26	15.6	43.5
16044	Concon, Camino Internacional	ECP (Bato)	Coastal	uk	Adult (40-50)	-15.4	8.9	7.0	3.25	15.3	42.7
16045	Concon, Camino Internacional	ECP (Bato)	Coastal	F?	Adult (45-55)	-15.4	9.3	4.7	3.24	14.0	38.9
16046	Papudo	ECP	Coastal	F	Adult (16-20)	-16.9	9.8	5.4	3.25	15.1	42.2
16047	Papudo	ECP	Coastal	F?	Adult	-16.3	14.5	4.4	3.21	15.4	42.3
16048	Papudo	ECP	Coastal	F	Adult	-18.7	10.9	13.5	3.21	15.6	43.0

16049	Calle Ricardo, Santa Cruz	ECP (Llolleo)	Inland	M	Adult	-14.7	5.8	7.1	3.24	8.9	24.8
16050	Calle Ricardo, Santa Cruz	ECP (Llolleo)	Inland	uk	Adult (45-55)	-19.3	5.0	3.5	3.21	12.6	34.7
16051	Calle Ricardo, Santa Cruz	ECP (Llolleo)	Inland	uk	Adult	-18.6	5.9	2.0	3.28	12.9	36.1
16052	Calle Ricardo, Santa Cruz	ECP (Llolleo)	Inland	M ?	Adult	-19.5	4.0	1.8	3.58	3.3	10.2
16053	Calle Ricardo, Santa Cruz	ECP (Llolleo)	Inland	M ?	Adult	-19.5	5.0	3.2	3.29	12.4	35.0
16054	Calle Ricardo, Santa Cruz	ECP (Llolleo)	Inland	uk	Adult	-19.1	5.2	5.4	3.24	11.6	32.3
16055	Calle Ricardo, Santa Cruz	ECP (Llolleo)	Inland	uk	Adult	-19.4	4.3	2.8	3.38	8.7	25.1
16056	S-Bato 1	ECP (Bato)	Coastal	uk	Adult	-18.2	10.9	4.9	3.35	13.8	39.5
16057	S-Bato 1	ECP (Bato)	Coastal	M ?	Adult (35-50)	-14.6	14.8	9.9	3.31	13.4	38.1
16058	Villa Alemana	LP (Aconcagua-Inka)	Inland	uk	Subadult (16.5-19.5)	*-16.0*	*4.2*	*1.4*	*3.86**	*1.6*	*5.2*
16059	Villa Alemana	LP (Aconcagua-Inka)	Inland	uk	Adult	-11.4	11.4	4.3	3.38	13.0	37.7
16060	Las Chilcas	ECP (Bato)	Inland	M	Adult (45-55)	-19.0	7.6	2.7	3.33	9.4	26.9
16061	Pocochay	ECP (Llolleo)	Inland	M	Adult (45-55)	-20.4	5.4	3.6	3.26	15.1	42.1
16062	Pocochay	ECP (Llolleo)	Inland	M ?	Adult (24-30)	-20.4	5.7	6.5	3.28	16.0	45.0

*Table 4: Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) results of human bone collagen samples. *Sample with unacceptable collagen quality criteria is recorded in italics.*

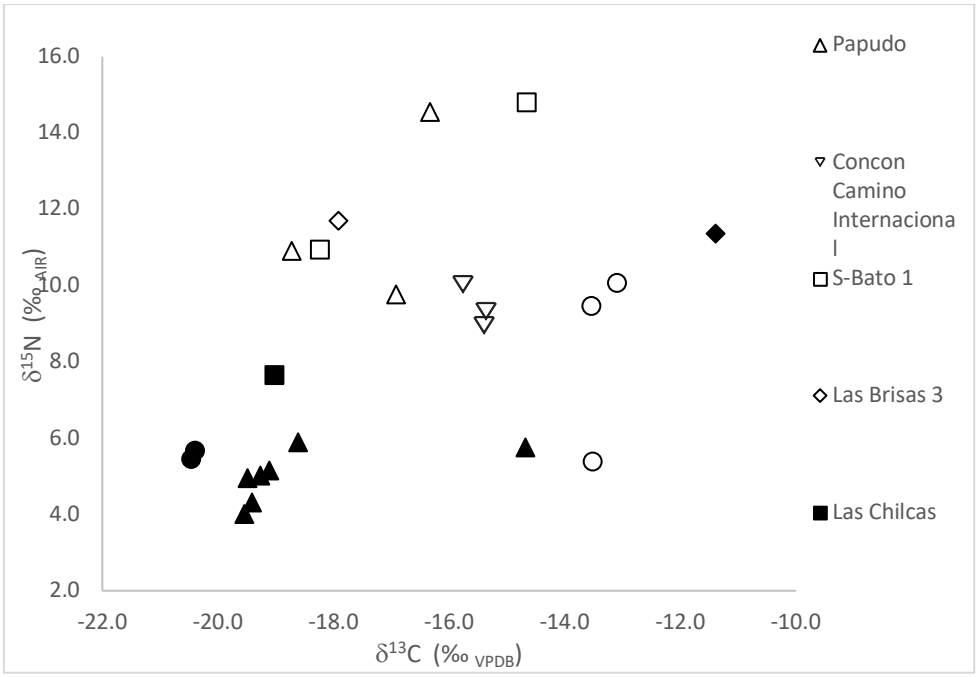


Figure 2: Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) results of human bone collagen samples represented by site. Hollow symbols represent coastal sites and solid symbols represent inland settings.

The $\delta^{15}N$ values for the inland individuals are quite low. The average human bone collagen values for $\delta^{15}N$ (5.9 ± 2.0 ‰) are similar to those measured for terrestrial herbivores (Lama guanicoe, mean $\delta^{15}N$ 5.0 ± 0.9 ‰) from the region (Falabella et al., 2007), rather than the +3.0 to 5.0 % higher that would be expected if humans were regularly consuming guanaco meat. The low $\delta^{15}N$ values observed in humans may be due to a negligible intake of animal protein among inland populations, although this would be contrary to the evidence from archaeological deposits, which include camelid remains and hunting equipment (Falabella et al., 2016; Ávalos and Saunier, 2011). Considering the known availability of various beans (Phaseolous spp.) and peanuts (Arachis hypogaea) in Central Chile (Pardo and Pizarro, 2013; Planella and Tagle, 2004), another explanation could be that nitrogen-fixing legumes featured regularly in the local diet, thus lowering the $\delta^{15}N$ bone collagen values in consumers.

Setting	Temporal Period	*n*	Mean $\delta^{13}C$ (‰)	Range	Mean $\delta^{15}N$ (‰)	Range
This Study						
Coast	Early Ceramic Period	9	-16.6 ± 1.4	-18.7 to -14.6	11.2 ± 2.1	8.9 to 14.8
	Late Intermediate Period	3	-13.4 ± 0.2	-13.5 to -13.1	8.3 ± 2.5	5.4 to 10
Inland	Early Ceramic Period	10	-19.0 ± 1.6	-20.4 to -14.7	5.4 ± 1.0	4 to 7.6
	Late Period	1	-11.4		11.4	
*Previous Studies**						
Coast	Archaic	4	-18.7 ± 1.1	-19.8 to -17.6	10.2 ± 2.7	7.0 to 13.1
	Early Ceramic (Bato)	9	-18.0 ± 1.0	-19.9 to -16.6	9.8 ± 1.6	8.2 to 11.7
	Early Ceramic (Llolleo)	8	-15.0 ± 0.9	-16.2 to -13.5	10.6 ± 1.6	7.7 to 12.6
	Late Intermediate Period	8	-13.4 ± 1.9	-17.3 to -10.7	10.1 ± 2.2	8.1 to 14.3
Inland	Archaic	4	-18.7 ± 0.6	-19.2 to -17.9	8.8 ± 3.9	3.9 to 7.6
	Early Ceramic (Initial Ceramic Communities)	6	-20.1 ± 0.3	-20.3 to -19.6	4.5 ± 0.7	3.8 to 5.5
	Early Ceramic (Bato)	2	-18.4 ± 1.9	-19.7 to -17.0	6.1 ± 0.4	5.8 to 6.3
	Early Ceramic (Llolleo)	12	-14.1 ± 1.5	-17.6 to -12.7	5.8 ± 0.8	4.9 to 7.5
	Late Intermediate Period	18	-11.6 ± 0.8	-12.8 to -10.3	6.7 ± 1.0	5.0 to 8.1
	Late Period	15	-13.1 ± 1.2	-15.3 to -10.5	5.9 ± 1.0	4.4 to 8.5

*Table 5: Mean stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) values for temporal periods and geographic setting for human bone collagen samples from the Valparaíso Region. *The averaged isotopic values from previous Central Chilean studies adapted from Falabella et al. (2007); Falabella et al. (2008); Sanhueza and Falabella (2010); Tykot et al. (2009).*

The results for the material analysed have a wide $\delta^{13}C$ range (-20.4 ‰ to -11.4 ‰) demonstrating variability in subsistence strategies over time, with diets spanning from heavily C_3 dependent to a substantial contribution of C_4 foods (figure 3). Based on the earlier estimations of dietary endpoints for this region (-20.1 ‰ ± 2.9 for a 100% C_3 diet and approximately -4.7 ‰ for a 100% C_4 diet), it can be estimated that the range of $\delta^{13}C$ values from this study include diets which span from a 100% C_3 reliance in the Early Ceramic Period (such as those from Pocochay, where $\delta^{13}C$ = -20.4 ‰) through to an approximately 57% contribution of C_4 resources to the protein portion of the diet in the Late Period sample from Villa Alemana ($\delta^{13}C$ = -11.4 ‰).

There is a marked increase in $\delta^{13}C$ values from the Early Ceramic Period samples to the Late Intermediate Period and again to the Late Period, indicating the increasing inclusion of maize through successive temporal

periods. Similar between-group differences from the Santiago basin and Rancagua valley, have been used to argue that dietary practices are a defining feature of different cultural groups in the prehistory of the region (Falabella et al., 2007).

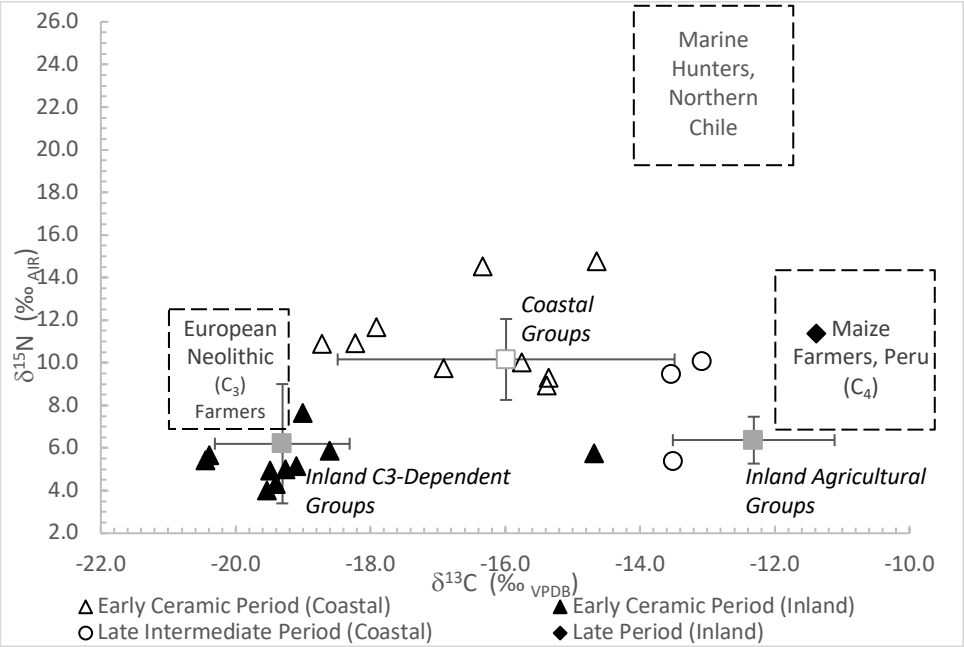


Figure 3: Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) results of human bone collagen samples from the Valparaíso Region represented by temporal period, accompanied by examples of human diets at extremes of the $\delta^{13}C$ and $\delta^{15}N$ spectrum (C_3, C_4, and high trophic-level marine), and comparative data from broad dietary groups identified in the neighbouring Santiago and Rancagua Regions. The mean values $\pm$ 1SD have been calculated for these groups from previously published data for Central Chile, combining inland Archaic Period and Early Ceramic Period (Initial Ceramic Communities and Bato) sites to represent "inland C_3-dependent groups", data from all coastal sites for "coastal groups", and combined data from inland Late Intermediate Period and Late Period sites to represent "inland agricultural groups" (after Falabella et al., 2007; Falabella et al., 2008; Sanhueza and Falabella, 2010; Tykot et al., 2009). Comparative dietary values for European farmers have been adapted from Schulting (2015), northern Chilean marine hunters from (Roberts et al., 2013), and maize farmers from Williams (2005) and Finucane et al. (2006).

4.1 EARLY CERAMIC PERIOD

There is no significant difference between the isotopic values for the inland Early Ceramic Period samples from this study when compared with the inland Early Ceramic Period (ICC, Bato and Llolleo combined) from the Santiago and Rancagua regions (p = 0.154 for $\delta^{13}C$ and p = 0.895 for $\delta^{15}N$, student's t tests). All but one sample (16049), have relatively low $\delta^{13}C$ and $\delta^{15}N$ indicating a C_3-dependent subsistence strategy, and fall within, or close to, the combined range of the identified C_3 consumers (Archaic Period, Initial Ceramic Communities and Bato) from Santiago and Rancagua.

Museum records indicate that Pocochay and Calle Ricardo are ascribed to the Llolleo tradition. Yet when compared with the inland Llolleo individuals from Santiago and Rancagua, the isotopic results for the Llolleo groups from the Aconcagua valley (Pocochay, Calle Ricardo) are significantly different for $\delta^{13}C$ ($p < 0.00001$, Mann-Whitney *U* test) though not for $\delta^{15}N$ ($p = 0.290$, student's *t* test) (Falabella et al., 2007). The Llolleo from the Santiago and Rancagua regions have much more elevated $\delta^{13}C$ values as a result of a mixed C_3-C_4 diet coinciding with the incipient cultivation of maize among these groups. There is, however, one individual among the Calle Ricardo samples (16049, $\delta^{13}C$ = -14.6 ‰ and $\delta^{15}N$ = 5.8 ‰) whose isotopic results fall within the same mixed C_3-C_4 resource Llolleo range known from further south.

These results from Pocochay and Calle Ricardo in the Aconcagua valley may represent very early Llolleo groups corresponding to a stage in the Early Ceramic Period when C_4 cultigens were not yet significantly exploited, or alternatively they may represent a prolonged persistence of hunter-gather subsistence strategies and primary dependence on C_3 resources in the region when compared to contemporaneous groups in Santiago and Rancagua. Without further contextual information for the Pocochay and Calle Ricardo sites, particularly regarding the duration these sites were in use and the age of the burials, it is difficult to speculate on the reason for the difference between the low trophic level C_3 diet for most of these individuals compared to other Llolleo sites from previous isotopic work.

Unlike the other inland Early Ceramic Period sites from the MHNV bioanthropology collection, the burials recovered from Las Chilcas have been attributed to the early stages of the Bato tradition (Hermosilla, 1994). One individual from this site was included in this study (16060), and evidently relied upon a C_3-based diet. However, this individual's $\delta^{15}N$ (7.6 ‰) is more elevated than those from the other inland Early Ceramic Period sites (Pocochay and Calle Ricardo). The slightly elevated $\delta^{15}N$ in this individual may reflect the regular exploitation of wild herbivores; typically a greater frequency of hunting equipment, particularly lithic points, is recorded at Bato sites in the broader Central Chilean region and a greater frequency of grindstones at Llolleo sites, suggesting the Bato were the more active hunters (Falabella et al., 2016). Various projectile

points were recorded during the excavation at Las Chilcas, along with seed and plant remains, as well as the presence of some marine mollusc shells (Hermosilla, 1994).

The results from the coastal Early Ceramic Period samples from this study fall largely within the same $\delta^{13}C$ and $\delta^{15}N$ ranges as the published data for coastal groups in Central Chile (Falabella et al., 2007). However, it is noted that on average the $\delta^{13}C$ values from this study are intermediate to the previous data when examined by cultural affiliation (Bato and Llolleo). Concon, Camino Internacional, Las Brisas 3 and S-Bato 1 have all been attributed to the Bato cultural complex (Carmona et al., 2001; Seelenfreund and Westfall, 2000; Novoa, 1999; Hurtado, 2003). However, the $\delta^{13}C$ results for the coastal ECP sites in this study are significantly different from the previously published results for both coastal Bato (p = 0.027, student's t test) and coastal Llolleo (p = 0.017, student's t test).

Except for Las Brisas 3, located near the mouth of the Maipo River, the coastal Early Ceramic Period sites in this study all lie much further to the north, around the Aconcagua and La Ligua Rivers. The remains of wild C_3 plants and seeds have been recorded in hearths of coastal Early Ceramic Period sites around the mouth of the Aconcagua, as well as significant quantities of *Lama guanicoe* bone (Carmona et al., 2001). Middens include various species of marine molluscs, fish, marine birds and sea lion (*Otaria flavescens*) (Seelenfreund, 2006; Seelenfreund and Westfall, 2000; Carmona et al., 2001). The relative frequency and variety of marine species at these sites suggest collecting molluscs and fishing were important means of subsistence for these groups.

4.2 LATE INTERMEDIATE PERIOD

The samples from the Late Intermediate Period are represented by three individuals from the coastal site of Las Brisas 10-14, associated with the Aconcagua cultural complex. The previously published isotopic data for the coastal Late Intermediate Period from Central Chile includes six other individuals from this site, and two from nearby sites at Tejas Verdes 5 and Santo Domingo 1 (Falabella et al., 2007). Both $\delta^{13}C$ and $\delta^{15}N$ values

for the three coastal Late Intermediate Period from this study coincide with previous results for this period and setting, showing no statistically significant difference ($\delta^{13}C$ $p = 0.971$, $\delta^{15}N$ $p = 0.279$, student's t tests).

The Las Brisas 10-14 results reveal more elevated $\delta^{13}C$ values compared to the Early Ceramic Period samples. These results are consistent with the increased reliance on maize as a staple crop during the Late Intermediate Period. Despite being located on the coast, one of the individuals from this site (16040), with lower $\delta^{15}N$, appears to have been consuming a largely terrestrial diet. Isotopic values for this individual ($\delta^{13}C$ = -13.5; $\delta^{15}N$ = 5.4) correspond more closely to those from inland agricultural groups on the Maipo and Mapocho Rivers during the Late Period (Falabella et al., 2008). One possible explanation for this individual's lower $\delta^{15}N$ is that they may have more recently arrived to the coastal setting of Las Brisas, located near around the mouth of the Maipo River, having previously lived and consumed a diet from further inland, which is still reflected in the averaged dietary isotopic values from bone collagen relating to the last several years of this individual's life.

The other two individuals from Las Brisas 10-14 have $\delta^{15}N$ levels more consistent with other coastal sites from this study and the broader region, indicative of a diet incorporating some marine resources. A maize-based diet, supplemented by some marine food corresponds with the known shift towards maize dependence during this period, as well as the presence of shell middens containing various species of molluscs recorded during the excavation of this site (Hurtado, 2003; Novoa, 1999; Seelenfreund et al., 2000; Westfall, 1999).

4.3 LATE PERIOD

There was only one Late Period sample, from the inland site Villa Alemana, which yielded results for this study. The context for this burial and the broader archaeological site associates it with Aconcagua-Inka and Diaguita-Inka influence as observed in the material culture, particularly the ceramic offerings (Vera Villarroel, 1985; Leguás Contreras, 2013). The $\delta^{13}C$ and $\delta^{15}N$ values for this individual are indicative of a diet reliant on

C_4 resources. Indeed, the isotopic data for the Late Period burial from Villa Alemana fall within the range of those reported for maize farmers in Middle Horizon Peru (Finucane et al., 2006).

Both the $\delta^{13}C$ (-11.4 ‰), and particularly the $\delta^{15}N$ value (11.4 ‰), are somewhat different to the average observed values for the Late Period in the Santiago region ($\delta^{13}C$ = 13.1 ± 1.2 ‰ and $\delta^{15}N$ = 5.9 ± 1.0 ‰) (Falabella et al., 2008). The $\delta^{15}N$ value for this individual is the most elevated of all the inland sites and suggests an increased intake of C_4-fed animal protein, marine protein, or both. This individual had reached adulthood, so any impact of the nursing effect on raised $\delta^{15}N$ can be discounted here. Even though Villa Alemana is not a coastal site, it is located approximately 18 km from the ocean on the western edge of the coastal cordillera, which may have allowed easier access to coastal resources. The $\delta^{13}C$ value for this individual is the highest for all the samples analysed from the MHNV collection and indicative of substantial C_4 exploitation, possibly with some additional input from marine resources.

Previous isotopic data have revealed a reduction in the proportion of C_4 resources in the Late Period diet compared to the Late Intermediate Period. A potential difference in patterns of maize consumption during the Late Period between the Vaparaíso region and the Santiago and Rancagaua regions may have implications relating to the administration of the Inka empire in the broader Central Chilean region, and state-based control of production or supply of maize within the empire. However, with only one Late Period sample from this collection, it is not possible to say whether the elevated $\delta^{13}C$ and $\delta^{15}N$ values for this individual represent a general increase in maize consumption in the Valparaíso region during the Late Period and therefore different dietary practices during this period when compared to the Santiago region, or if this is just one individual with uniquely elevated $\delta^{13}C$ and $\delta^{15}N$ values for the geographical and temporal setting.

5. Conclusions

The results presented here provide evidence from stable isotopic analysis ($\delta^{13}C$ and $\delta^{15}N$ of human bone collagen) for dietary practices from the Early Ceramic Period through until the Late Period from both coastal and inland sites in the Valparaíso region of Central Chile. The analyses of these samples from the

bioanthropological collections of MHNV demonstrate variability in dietary practices and exploitation of resources over different temporal and geographic settings, particularly regarding the consumption of C_4 or marine resources.

Differences were observed between the diets of the individuals from coastal sites compared to inland sites. The moderately elevated $\delta^{15}N$ and $\delta^{13}C$ for coastal samples indicate that the inhabitants of this zone were including some marine resources alongside terrestrial resources in their diets, most likely those from lower trophic levels, such as molluscs. The low $\delta^{15}N$ values for the inland groups, on the other hand, suggest a terrestrial diet, which may have either been low in animal proteins or included regular consumption of nitrogen- fixing legumes. The wide range of $\delta^{13}C$ values for these samples also demonstrates the differing dietary practices across the samples included in this study, and particularly points towards an increasing inclusion of maize in the diet over time.

These results generally support many of the conclusions from previous isotopic research in the Santiago and Rancagua regions (Falabella et al., 2007; Falabella et al., 2008). However, some potential differences were observed in the dietary patterns from this region, which may be usefully explored though further stable isotopic analysis of additional material from within the Valparaíso region. For example, all but one of the samples from the Early Ceramic Period, including those identified by museum records as belonging to the Llolleo tradition, retained a strongly C_3 dependent terrestrial diet, whereas isotopic data for the Llolleo groups from Santiago and Rancagua indicate they were already adopting maize in their diets, as evidenced by more intermediate (mixed C_3 -C_4) $\delta^{13}C$ values. It is suggested that the ECP samples included in this study are either from the earlier stages of the Llolleo tradition, before a transition to maize farming, or represent a prolonged persistence of C_3 reliance in this region.

Furthermore, while there was only one sample from the Late Period included in this study, the results for this individual indicated a more maize-dependent diet in contrast to the dietary patterns previously observed in the Santiago and Rancagua basins where a distinct decrease of maize in the overall proportion

of the diet was noted for this period. Further isotopic analysis, coupled with additional contextual information and absolute dating, of material from other sites in the area will help to clarify some of these initial findings regarding prehistoric dietary practices in the Valparaíso region of Central Chile.

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CHAPTER 3: A RADIOCARBON CHRONOLOGY FOR ESTADIO DE QUILLOTA IN THE ACONCAGUA VALLEY, CENTRAL CHILE, WITH REFERENCE TO THE ADOPTION OF INTENSIVE MAIZE AGRICULTURE AND REVISITING THE TIMING OF INKA INFLUENCE ON THE SOUTHERN FRONTIER

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A RADIOCARBON CHRONOLOGY FOR ESTADIO DE QUILLOTA IN THE ACONCAGUA VALLEY, CENTRAL CHILE, WITH REFERENCE TO THE ADOPTION OF INTENSIVE MAIZE AGRICULTURE AND REVISITING THE TIMING OF INKA INFLUENCE ON THE SOUTHERN FRONTIER

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ABSTRACT. Estadio de Quillota (EDQ) is the largest known pre-Columbian cemetery site within the Aconcagua Valley of Central Chile. Despite its importance, existing chronological data for EDQ are limited and questions remain regarding the prehistory of the Valley, particularly around the adoption and intensification of maize agriculture, as well as the timing of Inka influence reaching the region. Seventeen new AMS radiocarbon dates presented here indicate two distinct phases of use at EDQ: An earlier phase (339–196 cal BC to cal AD 128–339), and a later phase (cal AD 1280–1387 to cal AD 1413–1458). Accompanying stable isotope ($\delta^{13}C$ and $\delta^{15}N$) analyses of human bone collagen (n=22) demonstrate diachronic dietary changes corresponding to these phases, with a reliance on terrestrial C_3 resources during the earlier period, followed by a heavy dependence on C_4-based (maize) resources during the later use. Bayesian modeling of the dates from Late Period contexts suggests Inka influence arrived in Central Chile by ca. cal AD 1400, decades before the date cited in traditional chronologies, AD 1471. Inka expansion likely occurred here with an initial phase of interaction and exchange preceding a later phase of integration. This finding supports growing evidence that the traditional chronology of the Inka Empire requires reconsideration.

KEYWORDS: Bayesian modeling, maize, stable carbon and nitrogen isotope analysis.

INTRODUCTION

Estadio de Quillota (EDQ) is the largest known pre-Columbian cemetery site within the Aconcagua Valley and has been described as one of the most important sites for the archaeology of Central Chile (Ávalos and Saunier 2011). The use of the cemetery has been presumed to be relatively continuous from at least the beginning of the Early Ceramic (ca. 300 BC), through until the Late Period when the region came under Inka influence (ca. AD 1450–1536) (Gajardo-Tobar and Silva 1970; Didier and Ávalos 2009a, 2009b). This time span encompasses an array of technological, social and cultural developments, from hunting and gathering, to the initial use of ceramics, early exploitation of cultigens, the intensification of maize (*Zea mays*) farming, and the burgeoning influence of the Inka Empire. The use of a cemetery at a single location seeing all of these developments would, in principle, provide an excellent opportunity to explore their impacts on human diet and health, changes in demographics, lifeways and mortuary practices. However, detailed contextual information for individual burials is lacking and existing chronological data for EDQ are limited. Questions remain regarding the history of the site and of the Aconcagua Valley, particularly around the timing and nature of the adoption and expansion of maize agriculture, as well as the timing of Inka influence in the region.

The Aconcagua Valley lies on the periphery of intensive maize agriculture in the Americas and also on the southern frontier of the Inka Empire. Despite the rich cultural heritage of the region, there are few existing radiocarbon dates for the large cemetery site at EDQ, or indeed the Aconcagua Valley, and a robust chronological framework is lacking. Much of the extant research and knowledge of the Valley's archaeology is confined to the excavation and salvage reports of specific sites, especially for the mid to lower reaches of

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the river system. Temporal associations have so far largely been assigned using ceramic typo-chronologies and thermoluminescence (TL) dating alongside limited radiocarbon dates (Sánchez et al. 2004; Ávalos and Saunier 2011; Cornejo 2014).

This paper aims to establish an initial radiocarbon chronology for EDQ and determine where it fits within the chronology of the Aconcagua river valley system. This is important in terms of providing a framework within which to address questions around the timing of socio-political transitions and variations in subsistence strategies in the Aconcagua Valley that warrant further investigation. To this end, we present a preliminary radiocarbon chronology for EDQ by dating human bone collagen from 17 selected burials. New dietary stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$) of human bone collagen for the EDQ burials with direct dates (including six pre-existing dates from Fuenzalida [2014]) are also presented to address dietary change.

Given the putative long timescale of burial at EDQ, stable isotope data from directly dated individuals can inform on changes in diet over time, particularly regarding the introduction and intensification of maize agriculture. The presence of culturally heterogeneous groups has been postulated for both EDQ and the Aconcagua Valley as a whole (Sánchez et al. 2004; Sánchez Romero 2004; Ávalos and Saunier 2011; Fuenzalida 2014). Limited previous stable isotope ($\delta^{13}C$ and $\delta^{15}N$) evidence supports this by demonstrating considerable dietary variability among pre-Columbian groups in the Valley, particularly concerning the consumption of maize and marine resources (Swift et al. 2017). The stable isotope data when combined with radiocarbon dating can also address the extent to which dietary variability is diachronic or synchronic, the latter suggesting that different communities with distinct dietary practices utilized the same cemetery to bury their dead (cf. Santana-Sagredo et al. 2015).

There is also a question around the timing of the arrival of Inka influence in Central Chile, on the southern frontier of the Empire. Traditionally, the southward expansion of the Inka Empire has been based on a date of AD 1471, though nowadays many sources place it some decades earlier, at ca. AD 1450 (Uribe and Sánchez 2016). However, Bayesian modeling of radiometric dates from other frontier regions of the Inka Empire in Ecuador and neighbouring regions of Argentina is increasingly suggesting that the traditional chronology of Inka expansion derived from the historical accounts of Spanish chroniclers may be incorrect (Ogburn 2012; Marsh et al. 2017). Of the EDQ burials with direct radiocarbon dates, nine have been identified as Late Period, of which seven were buried with "*Local Inka Phase*" ceramic offerings, the most abundant ceramic style observed in Late Period contexts (Fuenzalida 2014; Dávila et al. 2018). Direct dating of these burials should aid in clarifying the timing of the transition between the Late Intermediate Period and the Late Period, which saw the expansion of Inka influence into Central Chile.

The new radiocarbon dates, along with associated stable isotope analysis and chronometric modeling presented here provide a greater understanding not only of this important site and where it fits within the occupation sequence of the Valley, but also of the region's broader archaeology, and questions surrounding the use and control of food resources on the southern frontier of intensive maize agriculture in the Americas, as well as the expansion of the Inka into their southern frontier.

BACKGROUND

The Aconcagua Valley extends from the Andes in the east to the Pacific Ocean in the west and encompasses diverse ecological zones. Prehistoric sites have been recorded along the length of

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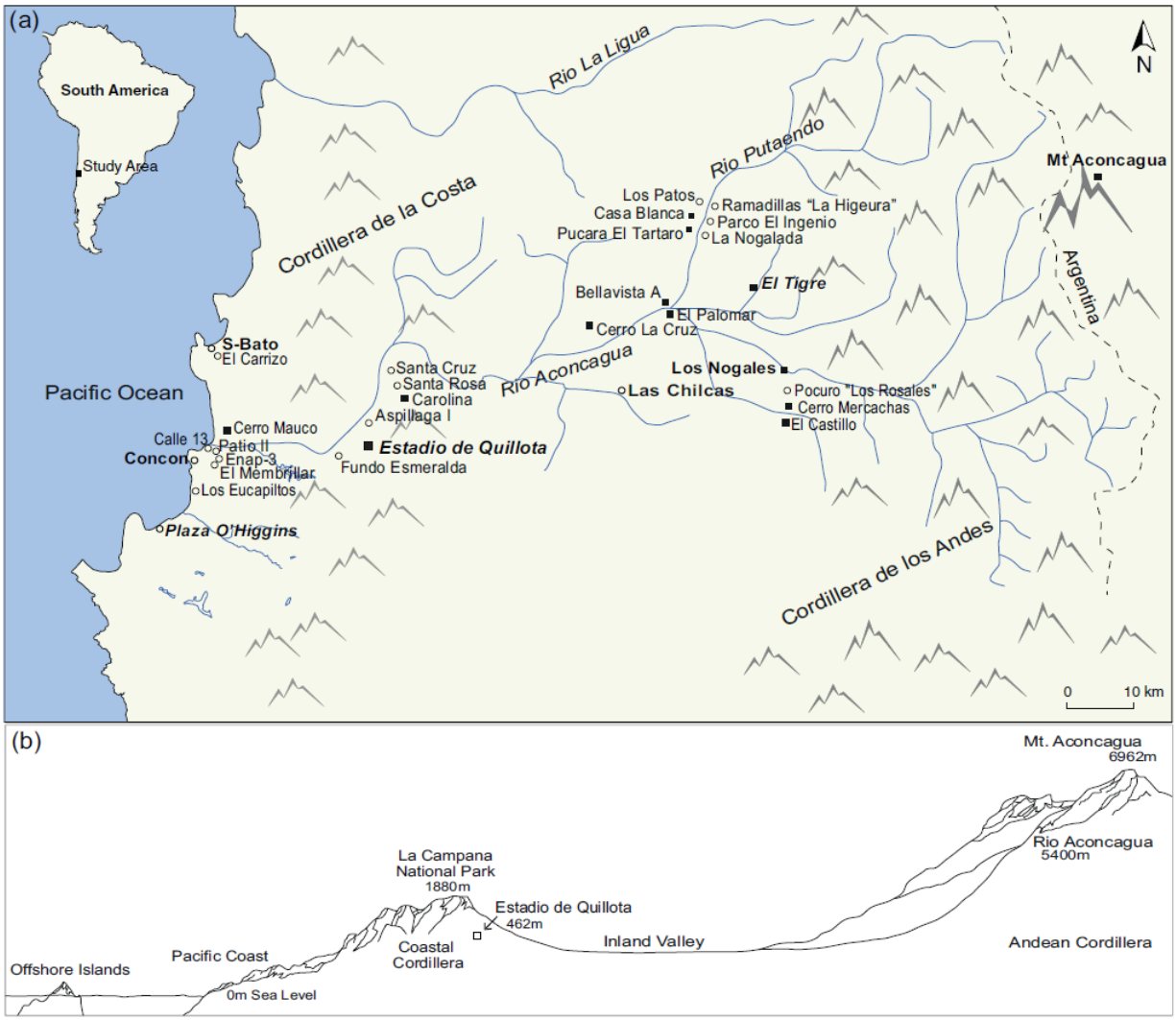


Figure 1 (a) Map of the study area showing Estadio de Quillota and other sites from which there are previously published thermoluminescence or radiocarbon dates. The sites represented with bold text have existing radiocarbon dates ($n = 8$). Site represented with italic text have both radiocarbon and thermoluminescence dates. Sites represented with a square symbol have identified Late Period/Inka contexts (n = 13). The remaining sites have only thermoluminescence dates (n = 24). (b) Cross-section (not to scale) depicting the diverse geographical zones of the Aconcagua River Valley system, and the location of Estadio de Quillota.

the river valley, the course of which can be divided into several geographic zones: the lower course, from the coast to the coastal cordillera; the middle course, which includes the broad, fertile inland valley area running from north to south between the coastal cordillera and the Andean cordillera; and the upper course, comprising the upper basin of the Aconcagua in the foothills of the Andes. The tumulos-style cemetery at Estadio de Quillota is situated on the inland side of the coastal cordillera on the broad fluvial terrace of the middle course of the Aconcagua River. It is located within the modern city of Quillota, approximately 83 km northwest of Santiago, and 38 km northeast of the port city of Valparaíso (Figure 1).

There have been multiple excavations at EDQ beginning in 1955–1956 (Gajardo-Tobar and Silva 1970) with subsequent commercial salvage excavations in 2009 and 2010 (Didier and Ávalos 2009a, 2009b; Baeza 2010). Over 200 burials have been excavated, estimated to represent only a proportion of the total number at the site. Human remains have also been

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recovered from salvage excavations at the adjoining site of Calle Arauco, which forms an extension of the EDQ cemetery, and is also included in this study.

It is thought that EDQ, the largest cemetery in the region, was in use from the Early Ceramic Period (ECP) (ca. 300 BC–AD 1000/1200), through the Late Intermediate Period (LIP) (ca. AD 1000/1200 –1450), and into the Late Period (LP) (ca. AD 1450–1536) (Gajardo-Tobar and Silva 1970; Didier and Ávalos 2009a; Baeza 2010; Ávalos and Saunier 2011). The Late Holocene in Central Chile, from ECP to LP, has been characterised by heterogeneous enclaves of at least partly contemporaneous local cultures (Bato, Llolleo and Aconcagua) alongside other cultural groups that expanded into the area from the semi-arid north, such as the Diaguita, followed by the expanding influence of the Inka Empire (Sánchez et al. 2004; Ávalos and Saunier 2011; Falabella et al. 2016; Uribe and Sánchez 2016) (Table 1).

The contextual information available for individual burials at EDQ is extremely limited, largely due to the time constraints of salvage excavations. However, analysis of the ceramics from a subset of the burials (Fuenzalida 2014), combined with limited descriptions and photographs of other burials has allowed for the attribution of some individuals to the Early Ceramic (ECP), Late Intermediate (LIP) and Late Periods (LP). LP ceramics, specifically of the "*Local Inka Phase*" style, have been identified from the grave goods of seven of the 23 individuals included in this study, and radiocarbon dates have previously been reported for six of those individuals (Fuenzalida 2014), confirming use of the site into the early 15th century. Two thermoluminescence dates from pots not associated with burials have also been reported from one of the previous excavations: an anthropomorphic jug from the ECP (AD 405 ± 170) (typical of the Llolleo culture) and a cup with a stepped trichrome motif, identifiable as an LP style (AD 1420 ± 45) (reported without lab codes in Didier and Ávalos 2009a).

Grave goods at EDQ mainly comprised pottery of varying forms, the majority being locally produced ceramics such as "*Aconcagua Local*" or "*Local Inka Phase*" (Fuenzalida 2014). External influences, predominantly from the Diaguita culture of the semi-arid north, but also from the Inka are described in LP burials (Gajardo-Tobar and Silva 1970; Didier and Ávalos 2009a; Baeza 2010). Other burial offerings included ceramic pipes, bone instruments, copper and stone jewellery, stone tools and projectile points. The presence of pipes, in particular, has led to an interpretation of special ritual and spiritual significance for this site (Ávalos and Saunier 2011).

Excavation reports note three distinct strata across the site at EDQ (Gajardo-Tobar and Silva 1970; Baeza 2010); however, this information is not available for each individual burial. It is recorded that burials from the upper two strata have been attributed to the LIP and LP, with many interred in tumuli with stones surrounding the body. These burials were often also accompanied by funerary ceramics with many of the LP burial offerings demonstrating influence of Diaguita and Inka styles (Gajardo-Tobar and Silva 1970; Didier and Ávalos 2009b; Baeza 2010). The majority of LIP and LP burials were in a prone position, but some were supine, with body and limbs extended and typically oriented with the head pointing east or northeast. Burials attributed to the ECP, on the other hand, were generally found in the lowest strata and interred in a flexed position. Many burials, however, were considerably damaged due to previous construction work on the site, meaning that burial position often could not be recorded during excavation.

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Table 1 Summary of chronological and cultural phases in the Aconcagua Valley from the Early Ceramic Period to the Late Period (see also Sánchez et al. 2004; Ávalos and Saunier 2011; Falabella et al. 2016a, 2016b; Uribe and Sánchez 2016).

Temporal Period	Culture	Description
Early Ceramic Period (ca. 300 BC–AD 1000/1200)	Initial Ceramic Communities (ca. 300 BC–AD 200) Bato (ca. AD 200–1000) Llolleo (ca. AD 200–1200)	• Ceramics appear in the archaeological record. • Small, heterogeneous groups of people coexisted in the same region, while maintaining different subsistence practices, material culture, funerary practices and settlement patterns. • The Initial Ceramic Communities (ICC) were primarily dependent upon wild (C_3) plant resources, although the presence of quinoa has also been recorded at some ICC sites. • The Bato largely practiced a hunter-gatherer lifestyle with some degree of territorial mobility and a reliance on near-shore, low-trophic-level marine foods, wild camelids and wild plant resources, with some incipient use of emerging domesticates. • The Llolleo co-existed alongside the Bato, although they are regarded as more sedentary and with a greater focus on cultigens. Small, self-sufficient groups with a collective Llolleo identity established dispersed settlements throughout the middle and upper sequence of the Aconcagua Valley.
Late Intermediate Period (ca. AD 1000/1200–1450)	Aconcagua	• Settlements generally located along fluvial terraces of inland valleys and comprised a few residential units. • Little or no social stratification. • Fields for cultivating crops situated adjacent to habitation areas. • Designated spaces for processing food and the production of lithics and pottery.

(Continued)

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Table 1 (*Continued*)

Temporal Period	Culture	Description
Late Period (ca. AD 1450–1536)	Aconcagua Diaguita Diaguita-Inka	• Synonymous with and characterized by an Inka presence in Central Chile. • Existing local Aconcagua culture persisted into the Late Period (LP). • Presence of Diaguita groups (from the semi-arid north of Chile) noted in Central Chile, evidenced in differing burial practices and material culture (e.g., ceramics and metallurgy). • A more defined hierarchy was implemented with social units headed by local *caciques*, and previously dispersed communities were organized into small settlements. • Various forms of production were increased, including mining, increased management of domesticated camelids and further intensification of maize agriculture with introduction of irrigation.

Maize Agriculture in Central Chile

The appearance and subsequent intensification of maize agriculture in the archaeological record of the Americas is an important indicator of agricultural expansion and is often concomitant with social and political developments (Hastorf and Johannessen 1993; Emerson et al. 2005; Finucane et al. 2006; Gil et al. 2006). The South Central Andes (northwestern Argentina and Central to Central-South Chile) was home to some of the southernmost agriculturalists of South America, and the final region to adopt cultivation of pre-Hispanic crops (Gil 2003). The broad fertile river valleys of Central Chile were ideally suited for large-scale agriculture, with chroniclers from the post-contact period describing the Aconcagua Valley in particular as an epicentre for the production of maize (Frézier 1717). Yet the majority of Central Chilean archaeological research, including stable isotopic studies, has concentrated on the Maipo-Mapocho basin around Santiago and the Cachapoal river to the south (Falabella et al. 2016). The only previous isotopic study from the Aconcagua Valley incorporated a handful of sites from coastal and inland valley settings and found considerable variability in dietary practices from the ECP to the LP. This study found an increase in mean $\delta^{13}C$ values during the LIP, suggesting that intensification of maize took place during this period (Swift et al. 2017). Isotopic reconstructions of diet in the Maipo-Mapocho basin to the south indicate that some of the inland communities of the ECP were among the first in Central Chile to adopt maize (Falabella et al. 2008). However, intensive maize agriculture did not appear until ca. AD 1000-1200 (Falabella et al. 2008, 2016).

Stable carbon and nitrogen isotopic analyses are particularly suited to answering questions regarding the consumption of maize. Most wild plants and cultigens follow a C_3 photosynthetic pathway, while maize uses the C_4 pathway. The $\delta^{13}C$ signature of C_4 plants is distinct from C_3 plants, such that incorporation of maize in the diet will result in significantly elevated stable carbon isotope values in body tissues. Maize is the most important Americas cereal and often recognized as the only C_4 plant contributing significantly to diet in Central Chile (Falabella et al. 2020). However, in southern Peru, Cadwallader et al. (2012) have identified various other C_4 plants from the *Graminae*, *Chenopodiaceae*, *Asteraceae* and *Amaranthaceae* families, which include several important edible plants for both humans and animals. Hence, the possibility of C_4 plants other than maize contributing to elevated $\delta^{13}C$ values cannot be entirely excluded, though there is no palaeobotanical evidence for intensive use of C_4 plants apart from *Zea mays*.

Stable nitrogen ($\delta^{15}N$) isotope analysis complements the interpretation of the $\delta^{13}C$ data by providing information about dietary trophic level, which can be useful in distinguishing mixed C_3-C_4 terrestrial diets from mixed marine diets. However, it is important to bear in mind that some agricultural practices, such as fertilizing crops, can substantially raise $\delta^{15}N$ values in horticultural produce (Szpak et al. 2012; Santana-Sagredo et al. 2021). Climate changes can also cause variation in $\delta^{15}N$, with increased aridity, and $\delta^{13}C$, with proportional variations in C_4 plants linked to temperature. Central Chile is subject to a Mediterranean climate with dry summers and wet winters. The current climatic conditions have remained much the same for the last 3000 years with seasonal and inter-annual variations in rainfall influenced by El Niño Southern Oscillation fluctuations (Villagrán and Varela 1990; Jenny et al. 2002; Villa-Martínez et al. 2003).

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The Inka Empire in the Aconcagua Valley

The Inka Empire, *Tawantinsuyu*, the "Land of the Four Quarters," comprised four regions of expansion: *Antisuyu*, *Cuntisuyu*, *Chinchasuyu* and *Collasuyu*, with Cuzco located at the nexus of the quarters. *Collasuyu* was the southernmost and the largest quarter of the Empire, incorporating parts of modern southern Peru, western Bolivia, northwestern Argentina, northern Chile and extending as far south as Central Chile (Moseley 2001; D'Altroy 2002). The Aconcagua Valley of Central Chile held strategic significance in the Inka State during the Late Period as an administrative centre for the southern reaches of the Empire (Mariño de Lobera 1970 [1580]; Vivar 1988 [1558]; Valdivia 1991 [1555]; de Góngora Marmolejo 2010 [1524-1575]).

Inka control of Central Chile is generally held to have been via a system of indirect government (Silva 1978; Falabella 1994; Stehberg 1995; Uribe 2000; Sánchez Romero 2002; Hermosilla et al. 2005). Recent discussions surrounding the nature of the expansion of *Tawantinsuyu* into the Maipo-Mapocho basin surrounding Santiago have presented arguments for an initial phase of Inka influence in the region, followed by a secondary phase of Imperial occupation (eg. Alconini 2016; Dávila et al. 2018; Pavlovic et al. 2019; Mundt and Marsh 2021). In the Aconcagua Valley it is proposed that the initial phase of Inka influence involved varied interaction between the Inka and the local populations and included the circulation of ideas, material culture, political negotiation and redistribution, while the subsequent phase saw the consolidation of Central Chile into the Empire's southern frontier and the appearance of Inka structures, *tambos* (state-owned lodgings located on Inka roads), *qollqas* (storehouses), *pukaras* (fortified sites), *huacas* (shrines), high altitude ceremonial sites and cemeteries. Such Inka emplacements are present at various intervals along the Aconcagua Valley from coast to mountains (Coros and Coros 1999; Sánchez Romero 2002, 2004; Troncoso et al. 2012; Pavlovic et al. 2014; Dávila et al. 2018).

The existing local culture, the Aconcagua, persisted into the early stages of the Late Period, but exhibited signs of "foreign" Diaguita and Inka influences in their material culture. The heterogeneity observed in Late Period ceramic morphology and technology has been interpreted as a representation of different degrees of local integration with the Inka State, where principles of exclusion and inclusion operated between *Tawantinsuyu* and different local communities (Martínez 2011; Fuenzalida 2014; Dávila et al. 2018; Pavlovic et al. 2019). A burgeoning Inka occupation subsequently saw various Imperial structures used for ceremonial, defensive and administrative purposes established at strategic points along the river valleys and longitudinal roads (Stehberg 1995; Coros and Coros 1999; Troncoso et al. 2012).

Even though such a substantial Inka presence has been recorded in the Aconcagua Valley from the coast to the Andes, systematic archaeological work in the inland valley along the midcourse of the Aconcagua River is scarce, despite the importance of this section of the valley. Rather, previous work has been concentrated in the upper basin of the Aconcagua. It has been postulated recently that the upper basin of the Aconcagua may have been the initial focus of imperial activity and the point of diffusion for Inka expansion in Central Chile (Mundt and Marsh 2021). However, this assertion is based on a compilation of TL dates, the reliability of which have been called into question in this region, with discrepancies in TL dates noted by several sources (Schiappacasse et al. 1991; Pavlovic et al. 2012; Marsh et al. 2021).

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Radiocarbon dating of Inka contexts has also been limited to the upper reaches of the Aconcagua at the sites of El Tigre, a site with monumental Inka architecture (Pavlovic et al. 2012), and Los Nogales, a domestic site where Inka metallurgical practices had been adopted (Plaza and Martinón-Torres 2015). The body of a frozen and naturally mummified child sacrificed in an Inka *capacocha* ritual has also been recovered from a high altitude ceremonial site on Mt Aconcagua, which lies over the modern border in Argentina but sits directly at the head of the Aconcagua Valley, and dated to cal AD 1407–1491 (GX-19991-AMS: 370 ± 70 ^{14}C yr BP; and Beta-88785: 480 ± 40 ^{14}C yr BP, 453 ± 35 ^{14}C yr BP, χ^2, T=1.8 (5%3.8)) (Fernández et al. 1999; Marsh et al. 2017). Each of these established sites is from the later phase of Imperial occupation in the region. However, there have been no efforts thus far towards radiocarbon dating earlier contexts likely to represent the initial dispersion of Inka influence into central Chile.

The traditional chronology of Inka expansion was derived from the historical accounts of Spanish chroniclers. In particular, the writings of Caballo Balboa (1951 [1586]) were accepted as reliable accounts and from these, a traditional chronology and succession of Inka kings was proposed by Rowe (1944, 1945). Despite some opposing views, Rowe's chronology dominated the argument and thus became the most widely accepted and utilized (Pärssinen 1992). According to this chronology, there was a pre-Imperial phase in Cuzco from ca. AD 1200 to 1438, after which the Inka began conquering nearby neighbouring regions of the four quarters under the reign of Pachacuti Inka Yupanqui. The majority of expansion south into *Collasuyu* supposedly took place after incursions north into Peru and Ecuador, and after Topa Inka Yupanqui succeeded his father, from AD 1471 to 1493 (Figure 2). However, the chronicle of Betanzos (1987 [1551]), which was published after Rowe had already determined his chronology, indicates that certain parts in the north of *Collasuyu* were incorporated into the Empire during the reign of Pachacuti Inka Yupanqui (ca. 1438–1463), and therefore several decades earlier than postulated by Rowe.

There is now growing evidence to support the hypothesis that the Inka may have expanded into the four quarters of *Tawantinsuyu* earlier than recorded in Rowe's chronology; various radiocarbon dates from Inka contexts indicate that the expansion of the Empire towards its southern limits may have taken place several decades before AD 1471 (Rodríguez et al. 1993; Williams and D'Altroy 1998; Raffino and Stehberg 1999; Sánchez Romero 2004; Hermosilla et al. 2005; Ogburn 2012; Cornejo 2014; Alconini 2016; Mundt and Marsh 2021). Recent Bayesian modeling of radiometric dates from other sites along the Empire's southern reaches in Argentina has also suggested an Inka presence up to 100 years earlier than the historically recorded date, with an estimated arrival of *cal AD 1350–1440 (95% probability)* (Marsh et al. 2017). These findings have been followed by calls for more radiometric dating of Inka contexts from frontier zones of the Empire, and have not only raised questions about the timing of the Inka expansion, but also the order in which each of the territories were subjugated by Inka forces (Ogburn 2012; Marsh et al. 2017).

MATERIALS AND METHODS

Samples of human bone were obtained from 23 individuals held in the Museo Historico-Arqueologico de Quillota's collections from the sites of Estadio de Quillota and Calle Arauco, two adjacent sites that formed part of the same pre-Columbian cemetery complex (Table 2; Figure 3). AMS radiocarbon dating was carried out on bone collagen for 17 of

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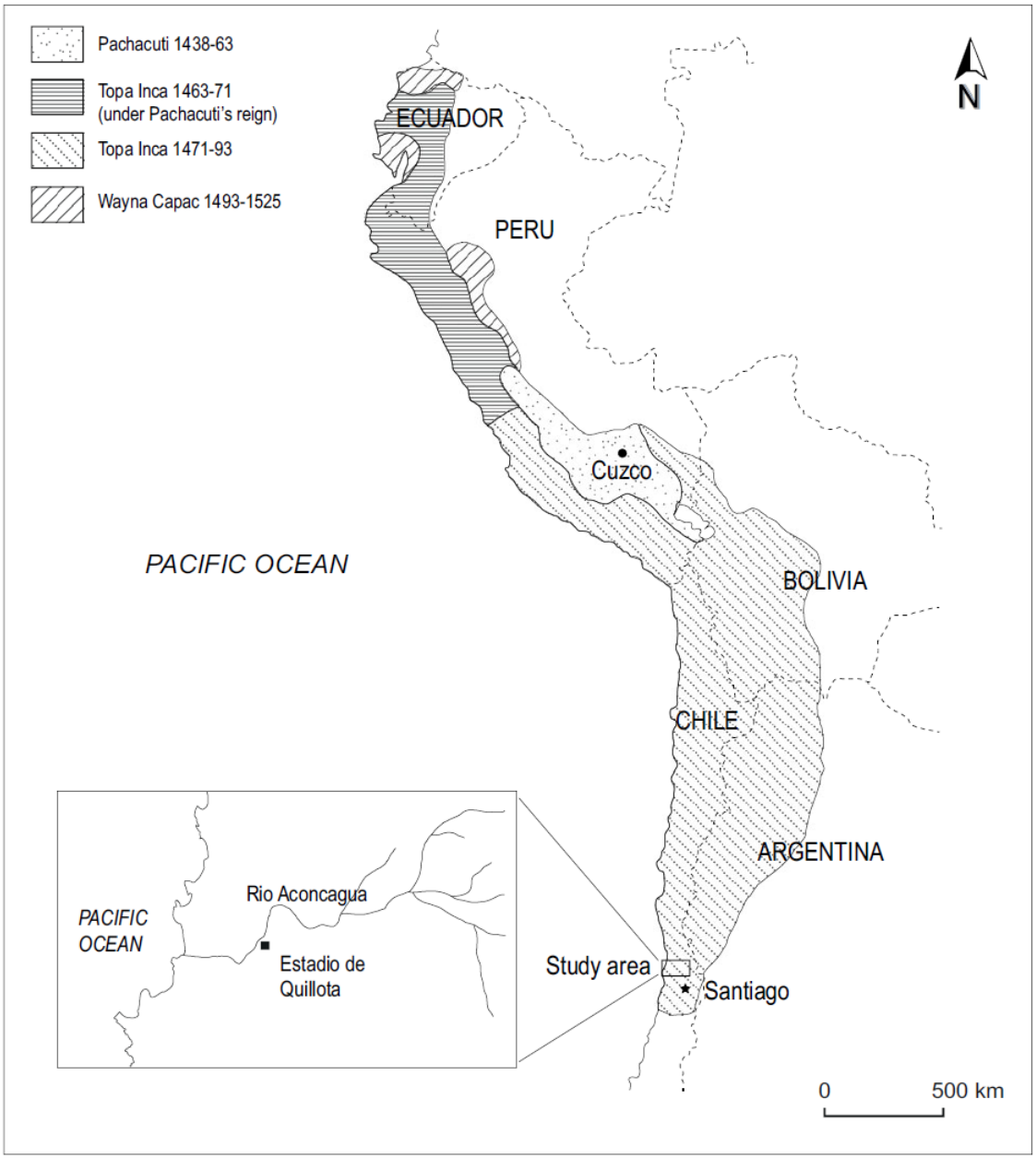


Figure 2 Map of the Inka Empire based on Rowe's (1944, 1945) chronology, depicting the phases of Imperial expansion under different Inka rulers according to the traditional chronology, with the southern expansion into *Collasuyu* taking place after much of the northern territories had already been integrated into the Empire.

the individuals, the remaining six of the 23 having been previously dated (Fuenzalida 2014), but lacking $\delta^{13}C$ and $\delta^{15}N$ measurements. Stable carbon and nitrogen isotope measurements were made separately for all 23 samples of human bone collagen.

The age-at-death of each individual sampled was estimated based on dental eruption for subadults (Ubelaker 1989) and dental attrition for adults (Lovejoy 1985). Sex was estimated, where possible, by morphological assessment of pelvic and skull fragments (Buikstra and Ubelaker 1994). Where available, information regarding burial location, position, orientation and grave goods was taken from the excavation reports (Baeza 2010). The human bone samples analyzed here derive from burials in four adjoining sectors of the

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cemetery. The majority of individuals at EDQ were buried in an extended prone position, which is reflected in the sample for radiocarbon dating. There is information available for 18 of the 23 individuals included in this study regarding burial position, with 13 in an extended prone position, one in an extended lateral to prone position, three in an extended supine position, and one in a flexed position.

Pretreatment and Collagen Extraction

Collagen was extracted from the bone samples using a modified Longin (1971) protocol. Bone fragments were cleaned by shot blasting with aluminium oxide pellets. Subsamples were crushed and demineralised in 0.5M HCl at 5°C for several days. The HCl solution was changed periodically until the samples ceased to produce observable CO_2. The demineralized samples were placed into sealed tubes of pH3 H_2O and gelatinized at 70°C for 48 hours. The supernatant was filtered to remove insoluble residue using 45–90 μm Ezee-filters™ and then freeze-dried for approximately 48 hours.

Stable Isotope Analysis

Approximately 1 mg of collagen for each of the samples was weighed into tin capsules. All samples were analyzed using a Sercon 20/22 Isotope Ratio Mass Spectrometer in continuous flow mode at the University of Oxford's Research Laboratory for Archaeology and the History of Art. All material was analyzed in duplicate to ensure reproducibility, with a precision greater than ± 0.2‰ based on repeat run of standards. Alanine standards of known value ($\delta^{13}C$ = –27.2 ± 0.1‰, $\delta^{15}N$ = 1.6 ± 0.2‰) were included at intervals throughout runs to allow for drift correction. Matrix-matched, in-house standards of cow ($\delta^{13}C$ = –24.3 ± 0.1‰, $\delta^{15}N$ = 7.9 ± 0.2‰) and seal collagen ($\delta^{13}C$ = –12.5 ± 0.1‰, $\delta^{15}N$ = 16.1 ± 0.2‰) were also included to allow for two-point calibration of the results (Coplen et al. 2006). The mean calibrated $\delta^{13}C$ and $\delta^{15}N$ measurements for all samples are reported in units per mil (‰) relative to international standards for $\delta^{13}C$ (VPDB) and $\delta^{15}N$ (AIR).

AMS Radiocarbon Dating

Approximately 5 mg of collagen from the 17 samples to be dated were combusted, graphitised and pressed into targets following routine protocol for the Oxford Radiocarbon Accelerators Unit (ORAU) (Brock et al. 2010). Collagen was prepared following the protocol outlined above and was not subjected to ultrafiltration. Radiocarbon dating was undertaken at ORAU's High Voltage Engineering Europa (HVEE) AMS. The resulting stable isotope corrected ^{14}C dates were calculated following Bronk Ramsey et al. (2004).

Calibration and Modeling

All calibrations and Bayesian models were determined using OxCal version 4.4 (Bronk Ramsey 2020). The radiocarbon dates were calibrated to a 95.4% probability range, using the SHCal20 Southern Hemisphere atmospheric curve (Hogg et al. 2020). Bayesian modeling utilizes a statistical approach to interpreting radiocarbon dates, incorporating assumptions known as priors, to constrain the resulting calibrated probability distributions for groups of dates (Bayliss and Bronk Ramsey 2004; Bronk Ramsey 2015). Bayesian modeling of prior assumptions alongside radiocarbon dates can be used to obtain improved chronological resolution for sites and events, e.g., the timing of Inka expansion. Kernel Density Estimates

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Table 2 Samples of human bone from Estadio de Quillota (samples with EDQ prefix) and Calle Arauco (Ar prefix) used for AMS radiocarbon dating, and $\delta^{13}C$ and $\delta^{15}N$ measurements.

Sample	Individual	Burial	Element	Sex	Age	Burial sector	Burial position	Burial direction	Burial offerings
Ar16016	1	.	Femur	F	Adult	CA	.	.	.
EDQ16077	23	13	Femur	F?	Adult	TA	Ext., Pr.	E	C^{LP}
EDQ16079	22	12	Rib	?	Adult	TA	Ext., Sup.	E	F
EDQ16081*	27	18	Tibia	?	Adult	TA	.	.	C^{LP}
EDQ16083	28	19	Rib	?	Sub-adult	TA	Ext., Pr.	NE	C
EDQ16099	43	27	Long bone	F	Adult	TA	Ext., Pr.	E	C, F, S, L
EDQ16101	46	29	Femur	?	Sub-adult	TA	Ext., Pr.	ENE	C
EDQ16104	48	30	Tibia	M?	Adult	TA	Ext., Pr.	NE	C, F
EDQ16107	57	32	Tibia	M	Adult	TA	Ext., Pr.	E	C^{LP}
EDQ17001*	60	36	Tibia	F?	Adult	TA	Ext., Pr.	E	C^{LP}
EDQ17005	65	40	Humerus	M	Adult	TA	Ext., Pr.	NE	C
EDQ17011*	75	43	Humerus	F?	Adult	TA	Ext, Sup.	ENE	C^{LP}
EDQ17012	88	45	Rib	M	Adult	TA	Ext., Pr.	E	C, S, L
EDQ17034	112	63	Femur	M	Adult	TA	Flexed	S	.
EDQ17037*	108	64	Humerus	F?	Adult	TA	Ext., Pr.	E	C^{LP}, S
EDQ17043*	114	67	Rib	F	Adult	TA	Ext., Pr.	NE	C^{LP}, L
EDQ17045	118	69	Humerus	F	Adult	TA	Ext., Lat. (L) to Pr.	N	C^{LP}, L
EDQ17047*	122	72	Rib	M?	Adult	TA	Ext., Pr.	N	C^{LP}
EDQ17052	127	74	Tibia	?	Adult	TA	.	.	.
EDQ17056	136	76	Rib	F	Adult	C	Ext., Pr.	.	.
EDQ17061	78	.	Tibia	?	Adult	TA	Ext., Sup.	E	C, F, L
EDQ17066	3	1	Tibia	?	Adult	TAS	.	.	C, L
EDQ17070	2	2	Cranium	M?	Adult	C	.	.	C

*Samples used only for $\delta^{13}C$ and $\delta^{15}N$ measurements, as radiocarbon dates for the same individuals are already provided in Fuenzalida (2014).Sex estimates include F = female, F? = probable female, ? = indeterminate sex, M? = probable male, M = male. Age categories include Adult = 18 years of age or older, Sub-adult = under 18 years of age. Recorded burial sectors include CA = Calle Arauco (Arauco Street), TA = Tribuna Andes (eastern grandstand), TAS = Tribuna Andes Sur (south-eastern grandstand), C = Cancha (playing field). Burial positions include Ext. = extended, Flexed = flexed, Pr.= prone, Sup. = supine, Lat. (L or R) = lateral (left or right side down). Burial direction records the cardinal direction towards which the individual's head was oriented. Burial offerings include C = ceramic (with unclassified temporal/cultural period), C^{LP} = Late Period ceramic, F = faunal remains, S = shell, L = lithic.

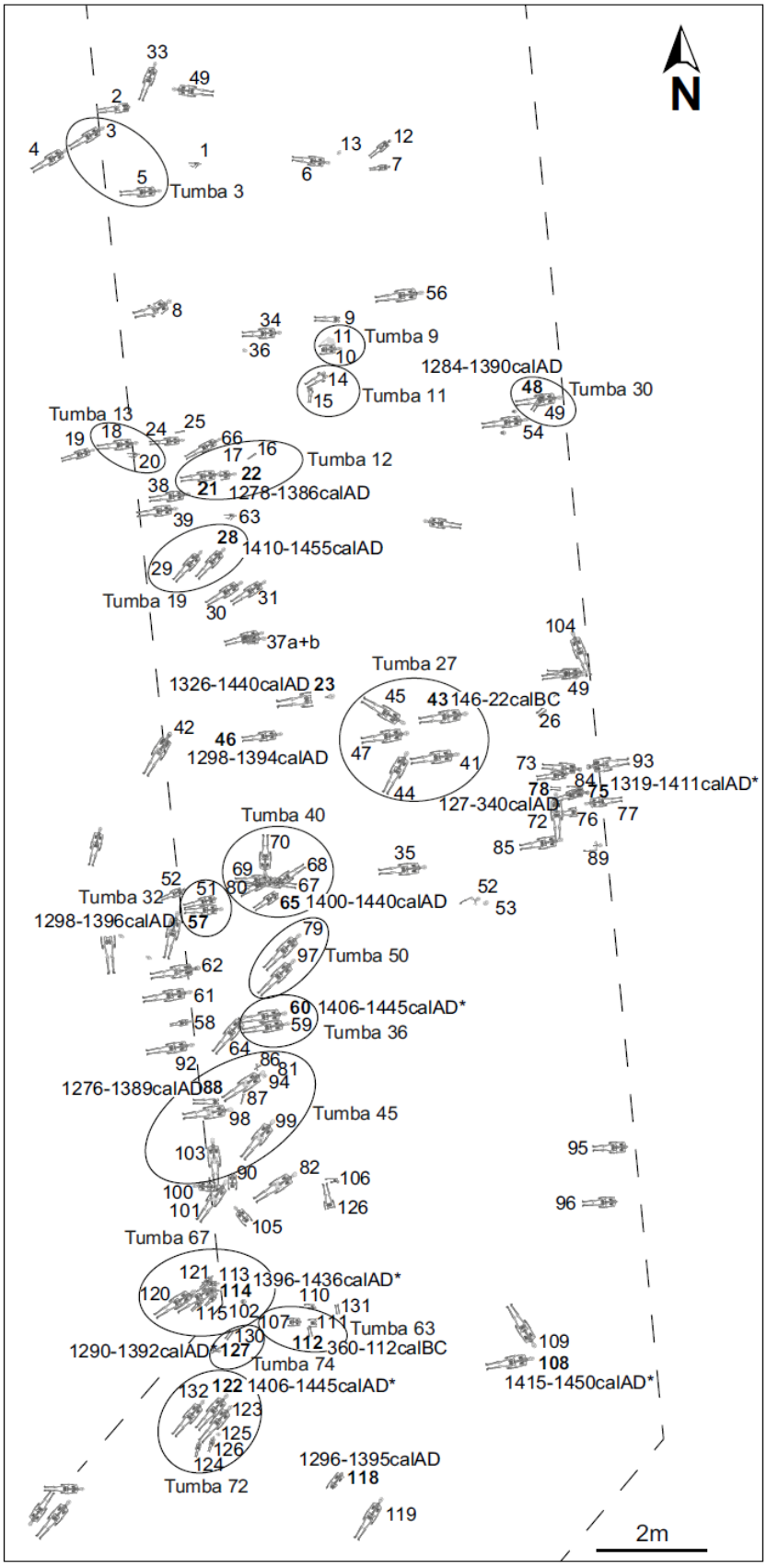


Figure 3 Site plan of Estadio de Quillota from 2009 excavations (adapted from Baeza 2010).

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are employed to create a continuous probability density distribution with modeled boundaries to summarise groups of dates (Bronk Ramsey 2017). Modeled results are presented in italics. Both individual dates and modeled ranges are presented at 95.4% confidence.

Statistics

Apart from the Bayesian modeling and Kernel Density Estimates of radiocarbon dates in OxCal 4.4, all other statistical analyses were carried out using R version 3.5.0 (RCoreTeam 2018) with RStudio 1.3.1056 (RStudioTeam 2020). Shapiro-Wilk tests indicated that subgroups of radiocarbon dates and stable isotopic data did not depart significantly from a normal distribution ($p > 0.05$). Therefore, parametric two-sided Student's t-tests were employed, with $\alpha = 0.05$, for all statistical comparisons of means.

Assessment of Collagen Quality

The quality of collagen preservation for both radiocarbon dating and stable isotope analysis was assessed by collagen yield (% wt greater than 1%), % wt of carbon and nitrogen relative to the combusted collagen (30–50% C; 11–16% N), and the atomic ratio of carbon to nitrogen (C:N between 2.9 and 3.6) (DeNiro 1985; Ambrose 1990; Van Klinken 1999; Brock et al. 2010). All collagen analyzed within this study, except for EDQ17037 (UGAMS 13208), fell within ranges indicating acceptable preservation. The stable isotope results for EDQ17037 and the corresponding previous radiocarbon date (UGAMS 13208), for which collagen quality data were not originally reported, were excluded from further analysis, interpretation and chronometric modeling.

RESULTS

Radiocarbon Dates

The new radiocarbon dates for Estadio de Quillota range from 399 to 196 cal BC (OxA-V-2735–19) to cal AD 1413–1458 (OxA-V-2735-18) (Table 3). The four earliest dates 339–196 cal BC to cal AD 128–339 (OxA-V-2737-44) are followed by a gap of roughly 1000 years before a cluster of 13 later dates between cal AD 1280–1387 (OxA-2730-55) and 1413–1458.

Stable Isotopes

The $\delta^{13}C$ results have a wide range from –21.5‰ to -8.4‰ ($\bar{X}$ = –12.8‰ ± 4.2, $n = 22$) (Table 3). The $\delta^{15}N$ results range from 4.4‰ to 8.6‰ ($\bar{X}$= 7.0‰ ± 1.3, $n = 22$). There is a strong positive linear correlation between $\delta^{13}C$ and $\delta^{15}N$ ($r^2 = 0.84$, $p < 0.001$). It is clear that the $\delta^{13}C$ and the $\delta^{15}N$ results are distributed bimodally with one smaller group of lower values ($\bar{X}$ $\delta^{13}C$ = –21.1‰ ± 0.5; $\delta^{15}N = 4.7$‰ ± 0.6, $n = 4$) and one of higher values ($\bar{X}$ $\delta^{13}C$ = –11.0‰ ± 1.4; $\delta^{15}N = 7.5$‰ ± 0.8, $n = 18$). The group of four lower $\delta^{13}C$ and $\delta^{15}N$ values corresponds to the four earlier radiocarbon dates reported above, while the group of higher values corresponds to the cluster of later dates. EDQ is an inland site and —despite the correlation between the two isotopes (see below)—there is no indication of any significant consumption of marine or freshwater resources that would skew the radiocarbon dates, meaning no reservoir corrections are necessary.

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Table 3 Radiocarbon dates and stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) results from the human bone collagen samples from Estadio de Quillota.

Lab code	Sample	Age[1]	Sex[2]	^{14}C yrs BP	±	Caibrated Date (95.4%)	Median (cal BC/ AD)	% Coll.	%C	%N	C:N	$\delta^{13}C$	$\delta^{15}N$
OxA V-2735-19	Ar16016	A	F	2311	30	399–196 cal BC	–273	10.0	45.1	16.1	3.3	–21.2	5.6
OxA V-2735-13	EDQ17034	A	M	2203	29	365–70 cal BC	–190	5.1	33.0	11.7	3.3	–21.5	4.4
OxA V-2730-57	EDQ16099	A	F	2095	29	146 cal BC–cal AD 22	–71	8.6	35.0	12.6	3.2	–21.1	4.5
OxA V-2737-44	EDQ17061	A	?	1837	30	cal AD 128–339	232	5.7	33.4	12.0	3.2	–20.4	4.4
OxA V-2730-55	EDQ16079	A	?	722	25	cal AD 1280–1387	1318	3.2	35.1	12.6	3.2	–12.6	6.7
OxA V-2735-12	EDQ17012	A	M	721	29	cal AD 1278–1389	1320	5.0	41.6	14.8	3.3	–9.6	7.6
OxA V-2735-9	EDQ16104	A	M?	702	26	cal AD 1285–1392	1349	6.3	35.6	12.6	3.3	–9.6	9.0
OxA V-2735-16	EDQ17056	A	F	693	28	cal AD 1287–1394	1348	3.5	33.6	11.9	3.3	–13.0	6.9
OxA V-2735-15	EDQ17052	A	?	690	28	cal AD 1290–1392	1348	3.2	36.2	13.1	3.2	–10.3	7.7
OxA V-2737-43	EDQ16101	SA	?	672	25	cal AD 1288–1394	1346	5.1	32.4	11.4	3.3	–13.7	6.6
OxA V-2735-14	EDQ17045^{LP}	A	F	672	27	cal AD 1296–1396	1346	3.9	35.2	12.7	3.2	–11.9	7.6
OxA V-2735-10	EDQ16107^{LP}	A	M	667	29	cal AD 1296–1398	1343	15.8	38.8	14.1	3.2	–10.2	8.1
UGAMS13205*	EDQ16081^{LP}	A	?	630	20	cal AD 1318–1408	1347	3.1	39.1	14.1	3.2	–9.4	8.6
UGAMS13207*	EDQ17011^{LP}	A	F?	620	20	cal AD 1320–1413	1346	3.4	26.9	9.6	3.3	–11.2	7.4
OxA V-2730-53 & 54~	EDQ16077^{LP}	A	F?	614 & 579	25	cal AD 1325–1424	1403	3.0	36.6	13.1	3.3	–10.5	7.9
OxA V-2735-17	EDQ17066	A	?	570	27	cal AD 1328–1444	1415	3.3	39.1	13.7	3.3	–11.5	7.2
UGAMS13209*	EDQ17043^{LP}	A	F	570	20	cal AD 1396–1439	1415	3.6	35.8	12.8	3.3	–11.2	6.4
OxA V-2742-15	EDQ17005	A	M	562	27	cal AD 1400–1443	1420	3.9	30.0	10.8	3.2	–8.4	8.3
UGAMS13206*	EDQ17001^{LP}	A	F?	540	20	cal AD 1407–1446	1427	2.4	15.9	5.2	3.6	–12.3	6.4
UGAMS13210*	EDQ17047^{LP}	A	M	540	20	cal AD 1407–1446	1427	2.9	39.4	13.7	3.4	–10.4	7.1

(Continued)

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Table 3 (*Continued*)

Lab code	Sample	Age[1]	Sex[2]	^{14}C yrs BP	±	Caibrated Date (95.4%)	Median (cal BC/ AD)	% Coll.	%C	%N	C:N	δ^{13}C	δ^{15}N
UGAMS13208*^	EDQ17037^{LP}	A	F?	*520*	*20*	cal AD *1416–1452*	*1436*	*0.8*	*1.8*	*0.4*	*4.9*	*–25.6*	*–1.7*
OxA V-2730-56	EDQ16083	SA	?	515	26	cal AD 1411–1455	1437	10.7	44.6	16.4	3.2	–11.0	7.6
OxA V-2735-18	EDQ17070	A	M?	507	27	cal AD 1413–1458	1439	5.5	40.5	14.4	3.3	–11.2	8.4

[1]Age categories include A (Adult) = 18 years of age or older, SA (Sub-adult) = under 18 years of age.

[2]Recorded sex estimates include F = female, F? = probable female, ? = indeterminate sex, M? = probable male, M = male. 'OxA V' designations refer to the fact that the collagen was not subjected to ultrafiltration.

*Dates with a UGAMS code originally reported in Fuenzalida (2014).

~As a random internal control, OxA V-2730-53 and OxA V-2730-54 (EDQ 16077) are duplicate dates from the same collagen sample and have been calibrated together using the R_combine function in OxCal 4.4 (χ^2 test: df=1 t=1.0(5% 3.8)).

[LP]Samples obtained from known Late Period burial contexts.

^The radiocarbon date and the isotopic data for EDQ17037 (UGAMS13208) were excluded from any further analysis due to poor collagen yield and quality. While falling within the expected date range, the radiocarbon date is also excluded from further consideration as collagen quality data were not reported when originally dated (Fuenzalida 2014).

DISCUSSION

Chronology of Estadio de Quillota

The radiocarbon dates from EDQ fall into two distinct phases of use, which correspond to the new isotopic data for dependence on maize-based resources, discussed further below. These two phases, with an interval of approximately 1000 years between them, contrast with previous expectations of a continuous and extended use of the cemetery. The samples were selected to provide coverage of the different sectors of the cemetery. However, a considerable number of burials are known to remain *in situ* at EDQ, so it is important to acknowledge that this 1000-year gap (which would correspond to the majority of the ECP and the first half of the LIP using the existing chronological framework for Central Chile) could be the result of a sampling bias. Future efforts towards conservation and analysis of the ceramics recovered from EDQ, coupled with further radiometric dating, would help to confirm the finding here of two distinct phases of use.

The earlier phase with four dates from 399–196 cal BC (OxA-V-2735-19) to cal AD 128–339 (OxA-V-2737-44) aligns with the beginning of the ECP in the existing Central Chilean chronological framework (ca. 300 BC–AD 1000/1200), particularly the period when the Initial Ceramic Communities (ICC) (ca. 300 BC–AD 200) appear in the archaeological record of the region. One of two available TL dates (AD 405 ± 170) for EDQ, from a Llolleo pot (Didier and Ávalos 2009a, reported without lab code), falls after this cluster of radiocarbon dates, but within the range of the Llolleo culture (ca. AD 200–1200).

Based on the current chronological framework for the region, the appearance of the ICC at the beginning of the ECP, for which the defining material correlate is the presence of ceramics, is assumed to have occurred around ca. 300 BC (Sanhueza and Falabella 1999). However, recent Bayesian modeling of the earliest dated ceramics from Central Chile indicates this technology most likely appeared around ~180 cal BC (Marsh 2017), coincident with other adjacent regions, suggesting that the current chronological framework requires some reconsideration regarding the commencement of the ECP.

The two more recent of the four dated individuals from this earlier phase of use at EDQ ((EDQ16099: 146 cal BC-cal AD 22 (OxA-V-2730-57) and EDQ17061: cal AD 128-339 (OxA- V-2737-44)) were recorded with ceramic offerings as well as lithics and faunal remains, and EDQ16099 was also found with shells. There are no further details regarding the pottery styles or descriptions of the other artefacts. However, these two new radiocarbon dates fall within Marsh's (2017) proposed starting boundary for the ECP in Central Chile around ~180 cal BC. Of the other two individuals from this earlier phase of use, EDQ17034 was not interred with any funerary offerings, and for Ar16016 there are no records to reveal whether any grave goods accompanied this burial.

A possible shift in the style of burial position may also be indicative of cultural differences. EDQ17034 was buried in a flexed position, which is characteristic of ECP and earlier burials. However, the site plan for EDQ suggests that EDQ16099 and EDQ17061 were buried in an extended position, a burial style more usually considered to be associated with LIP burials (Saunier and Ávalos 2010).

The early phase dates from EDQ are followed by a hiatus of ca. 1000 years before a later phase of 18 dates with a start boundary of *cal AD 1290–1380* to an end boundary of *cal AD 1420–1470* (Table 4). The cluster of later dates from EDQ is noticeably constrained with

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Table 4 Bayesian model of the later phase of use observed at Estadio de Quillota. A_{model}=95.7.

	Modeled (cal AD) (95.4%)		
Lab code	from	to	Median
Boundary Start Later Use	1290	1380	1346
R_Date OxA V-2730-55	1300	1390	1372
R_Date OxA V-2735-12	1300	1390	1372
R_Date OxA V-2735-9	1300	1400	1372
R_Date OxA V-2735-16	1310	1400	1372
R_Date OxA V-2735-15	1310	1400	1372
R_Date OxA V-2737-43	1320	1400	1375
R_Date OxA V-2735-14	1320	1400	1375
R_Date OxA V-2735-10	1320	1400	1377
R_Date UGAMS13205*	1320	1410	1392
R_Date UGAMS13207*	1320	1420	1395
R_Combine OxA V-2730-53 & 54	1330	1430	1404
R_Date OxA V-2735-17	1390	1440	1415
R_Date UGAMS13209*	1400	1440	1415
R_Date OxA V-2742-15	1400	1440	1417
R_Date UGAMS13206*	1410	1440	1425
R_Date UGAMS13210*	1410	1440	1425
R_Date OxA V-2730-56	1410	1450	1429
R_Date OxA V-2735-18	1410	1450	1430
Span of Later Use Phase	47	145	86
Boundary End Later Use	1420	1470	1441

this modeled phase lasting for a span of only *47 to 145 years* (95.4%). The later phase of use falls within what is currently accepted as the terminal stages of the LIP. However, eight of these burials are from LP contexts, seven of whom were buried with pottery defined as "*Local Inka Phase*" Aconcagua ceramics (Figure 4). "*Local Inka Phase*" ceramics are vessels made following the local (Aconcagua) pottery traditions, but with new decorative and morphological features (e.g., inscribed angles and handles attached to the lip), and the incorporation of other foreign references (e.g., Inka or Diaguita) (Fuenzalida 2014; Dávila et al. 2018). This suggests the transition to the LP and arrival of Inka influence may have occurred slightly earlier than the commonly used date of ca. cal AD 1450 (or the cal AD 1471 date from Rowe's chronology of Inka expansion) for the beginning of the LP.

A TL date of AD 1420 ± 45 from an LP vessel with a stepped trichrome pattern (Didier and Ávalos 2009a, reported without lab code) falls within the late cluster of new radiocarbon dates from EDQ and is another example of Inka influence appearing in the archaeological record and the transition to the LP occurring slightly before the currently accepted start date of ca. cal AD 1450. There are no further details available regarding the style of pottery found with the other individuals from the later phase of use at EDQ who were also recorded with ceramic grave offerings.

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Figure 4 Examples of ceramic pieces, two restricted vessels with necks, from Estadio de Quillota demonstrating stylistic differences between Late Intermediate Period ceramics in the Aconcagua Valley and *Local Inka Phase* ceramics of the Late Period (Photographs by N. Fuenzalida). (a) A Late Intermediate Period Aconcagua vessel with compound profile, spherical body, hyperboloid neck and a lip bonded strap handle from EDQ (ID 252-3) with both morphology and decoration typical of the Aconcagua Culture (Massone 1978). The black on Aconcagua salmon decorative motifs correspond to the triangles with tabs of the Aconcagua "trinacrio" design. (b) A *Local Inka Phase* vessel with compound profile, ellipsoid body, hyperboloid neck and two lip-bonded strap handles from EDQ (ID B1112). The burial which this vessel accompanied (Individual 27, burial 18, EDQ16081) has been directly dated to 1318–1408 cal AD (UGAMS 13205, Fuenzalida, 2014). The vessel has a local (lower course of the Aconcagua) morphology, but decorative features of the Diaguita (colours and bidirectional configuration) and Inka (the oblique reticulated motif arranged on the neck), with a stepped triangle and Greek key motif which is proportionally adapted to the form of the body (González 1995; Fuenzalida-Bahamondes 2021).

All of the individuals from this phase were buried in an extended position, mostly prone, but two were supine (EDQ16079 and EDQ17011), and one was lying on their left-hand side (EDQ17045). These trends are comparable to descriptions of burial patterns from other Central Chilean sites, in which flexed positions dominate in the ECP, and extended prone positions dominate in the LIP and LP (Saunier and Ávalos 2010).

Diet and Maize at Estadio de Quillota

The stable isotope results demonstrate a strong diachronic shift in dietary practices, particularly regarding the consumption of C_4 resources, i.e., maize. The inland location of the site (approximately 25km from the coast and on the inland side of the coastal cordillera) and the low $\delta^{15}N$ values indicate terrestrially based diets, with little or no input from marine resources. The wide range of $\delta^{13}C$ values (–21.5‰ to –8.4‰) particularly points towards increased inclusion of maize in the diet over time. There is a significant dietary split between the earlier and later phases of the burials dated at EDQ, with the four lower $\delta^{13}C$ and $\delta^{15}N$ values corresponding to the four earlier dates, and the higher $\delta^{13}C$ and $\delta^{15}N$ values corresponding to the later cluster of dates (Figure 5).

The relatively low mean $\delta^{13}C$ ($\bar{X} = -21.1‰ \pm 0.5$) of the earlier group indicates dependence on C_3-based resources, with little to no inclusion of maize in the diet. At this time, only *curagua*, an early endemic variety of maize, is known to have been present in the region (Planella et al.

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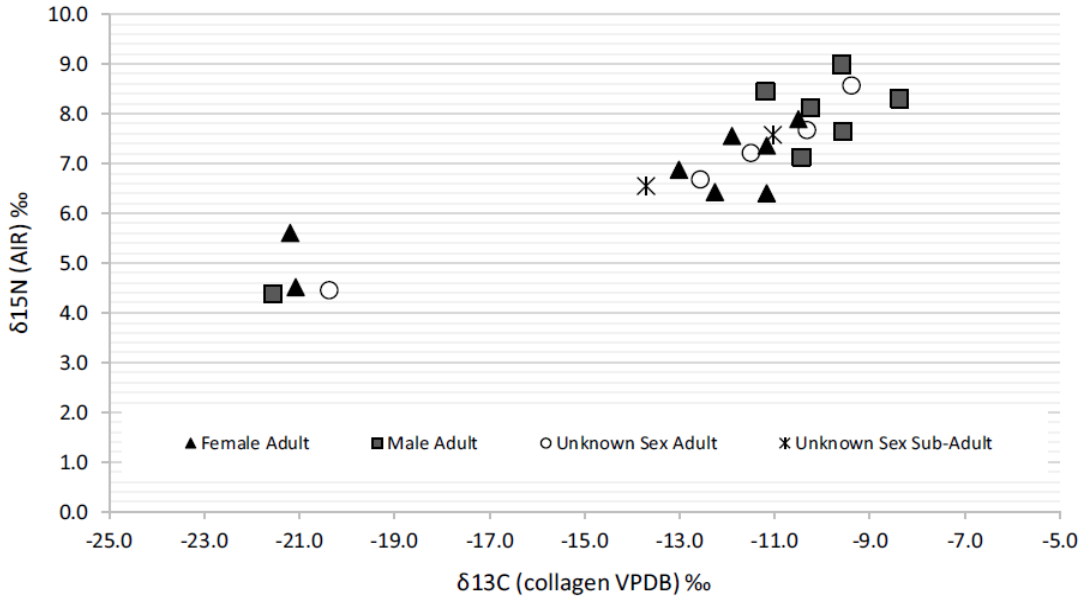


Figure 5 Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope results of human bone collagen samples from Estadio de Quillota.

2014). The isotopic results show no significant consumption of this or other wild C_4 grasses (cf. Cadwallader et al. 2012). The low mean $\delta^{15}N$ value ($\bar{X} = 4.7‰ \pm 0.6$) suggests a diet that was extremely low in animal proteins, possibly supplemented by the consumption of nitrogen-fixing legumes, which were present in Central Chile in several varieties of beans (*Phaseolus* spp.) and peanuts (*Arachis hypogaea*) (Planella and Tagle 2004; Pardo and Pizarro 2013). Since these would be expected to have $\delta^{15}N$ values near 0‰ (Tieszen and Chapman 1992), their consumption might be masking the contribution of animal protein; even so, it is unlikely to have been high. The isotopic results are similar to those previously observed at three other ECP sites in the inland valley of the Aconcagua Basin: Pocochay, Santa Cruz, and Las Chilcas ($\delta^{13}C = -19.0‰ \pm 1.6$, $\delta^{15}N = 5.4‰ \pm 1.0$, $n = 10$) (Swift et al. 2017), and to those more specifically identified as ICC (the initial cultural phase of the ECP) in the Maipo-Mapocho and Rancagua Basins immediately to the south of the study area ($\delta^{13}C = -20.1‰ \pm 0.3$, $\delta^{15}N = 4.5‰ \pm 0.7$, $n = 6$) (Falabella et al. 2007).

Even though incipient use of C_4 resources has been observed at some ECP sites in Santiago and Rancagua—usually those attributed to the Llolleo culture, a period not represented by the radiocarbon dates from Estadio de Quillota—it was not until the LIP and the arrival of the Aconcagua culture that a substantial uptake of maize is observed. This was followed by a marked intensification in the late 14th and early 15th centuries (Falabella et al. 2020), which is contemporary with the later phase of use at EDQ. The elevated $\delta^{13}C$ values ($\bar{X} = -11.0‰ \pm 1.4$) values among the group of 18 individuals from the later phase of EDQ likewise indicate a subsistence strategy that was heavily dependent on C_4 resources. The $\delta^{15}N$ values for this group ($\bar{X} = 7.5‰ \pm 0.8$) are also higher than those observed during the earlier phase of use at EDQ. A positive linear relationship between $\delta^{13}C$ and $\delta^{15}N$ data from EDQ suggests either an increasing inclusion of animal protein in the diet or the manuring of maize (cf. Spzak et al. 2012). The possibility of a marine component is discounted based on the low $\delta^{15}N$ values, the site's distance from the coast, the lack of evidence of fishing technology at the site, and the lack of zooarchaeological evidence of marine fish or shellfish.

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There was no significant difference between the $\delta^{13}C$ and $\delta^{15}N$ results for the individuals accompanied by "*Local Inka Phase*" Aconcagua pottery at EDQ ($n = 8$) compared to the other contemporary individuals lacking this affiliation ($n = 10$) ($\delta^{13}C$ $t = 0.30$, $p = 0.76$; $\delta^{15}N$ $t = -0.44$, $p = 0.67$). However, despite the small sample size, there is a significant difference observed between the sexes, with adult males ($n = 6$) being higher in both isotopes than adult females ($n = 6$) ($\delta^{13}C$ $t = -3.35$, $p = 0.01$; $\delta^{15}N$ $t = -2.63$, $p = 0.03$). This result suggests sex-based differential access to resources, with apparently greater availability of maize products and either higher trophic level protein sources, such as camelids foddered on maize stover, or increased access to fertilized maize crops for adult males when compared to adult females. A similar trend has recently been interpreted as greater consumption of maize-foddered camelids by adult males at sites ascribed to the Aconcagua culture further to the south (Falabella et al. 2020). Taken together, this indicates the possibility of widespread gendered patterns of maize consumption in Central Chile.

Chronology of the Aconcagua Valley

Existing TL and ^{14}C dates for the Aconcagua Valley have been collated in combination with the new dates from EDQ (see supplementary material Appendix A). This collation of dates establishes a sequence of use for the Aconcagua Valley and a span of approximately 7000 years with the earliest date from a coastal shell midden at the site of S-Bato 1 (5561–5474 cal BC; Beta128761 (Seelenfreund and Westfall 2000)) to the latest date from the occupation of El Tigre, an Inka site in the Upper Basin (cal AD 1501–1649; UGAMS5980 (Pavlovic et al. 2012)). The earliest dates predominately come from coastal sites, reflecting a similar pattern of use to that reported in the Maipo-Mapocho and Cachapoal Valleys of Central Chile, particularly in regards to earlier hunter-gatherers utilizing coastal sites and resources (Falabella et al. 2007).

The radiocarbon dates from EDQ fall within the constraints of the overall occupation sequence for the Aconcagua Valley. With only six sites in the inland valley of the Aconcagua having either ^{14}C or TL dates, there is a relative dearth of radiometric dates for the inland valley outside those presented here. In fact, there are no radiocarbon dates from any other inland valley sites apart from EDQ.

The Question of the Arrival of the Inka

Bayesian modeling of the radiocarbon dates for the eight identified LP burials at EDQ indicates the timing of the arrival of Inka influence to the Aconcagua Valley (Table 5). The start boundary for this model is *cal AD 1290–1400*. The end boundary is modeled as *cal AD 1410–1470*. Querying the chronometric model of these "*Local Inka Phase*" contexts using OxCal's "Difference" command demonstrates that Inka influence was likely present at EDQ from *73 to 189 years* before cal AD 1471, or from *50 to 160 years* before cal AD 1450. The model of Late Period contexts with "*Local Inka Phase*" ceramics at EDQ accords with previous estimates based on an accumulated probabilities model for arrival of the Inka in northern Chile by the late 14th century AD (Cornejo 2014).

Kernel Density Estimates were generated in OxCal to compare the ^{14}C dates from EDQ's later phase of use ($n = 18$), as well as the identified "*Local Inka Phase*" burials from EDQ ($n = 8$), with ^{14}C dates from other known Late Period contexts from the Aconcagua Valley ($n = 6$), and also the ^{14}C dates from other known Late Intermediate Period contexts from the Aconcagua

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Table 5 Bayesian model of the radiocarbon dates from identified Late Period burial contexts at EDQ. $A_{model} = 94.6$.

Lab code	Sample	Modeled (BC/AD) (95.4%) from	to	Median
Boundary Start Local Inka Phase Contexts		1290	1400	
Phase Local Inka Phase Contexts				
OxA V-2735-14	EDQ17045	1330	1410	1387
OxA V-2735-10	EDQ16107	1320	1410	1388
UGAMS13205	EDQ16081*	1330	1410	1395
UGAMS 13207	EDQ17011*	1330	1420	1397
OxA V-2730-53 & 54	EDQ16077	1390	1420	1404
UGAMS 13209	EDQ17043*	1400	1430	1413
UGAMS 13206	EDQ17001*	1400	1440	1420
UGAMS 13210	EDQ17047*	1400	1440	1420
Boundary End Local Inka Phase Contexts		1410	1470	
Difference Start Inka Influence at EDQ vs. AD1471		–189	–73	
Difference Start Inka Influence at EDQ vs. AD1450		–160	–50	

Valley ($n = 4$) (Appendix B). It is important to note that the sample size for some of the KDEs is very small, particularly for the LIP contexts with only four other ^{14}C dates available for comparison. This will have a large impact on the estimated start and end ranges. By contrast, there are approximately 35 TL dates from LIP contexts. Likewise, for the LP there are six ^{14}C dates and 25 TL dates. However, a different pattern is apparent for the TL dates compared to the ^{14}C dates in both the LIP and LP contexts and indeed there is a statistically significant difference in the median calibrated ^{14}C and TL dates (LIP $t = 3.59$, $p \leq 0.000$; LP $t = 3.16$, $p = 0.004$). A recent critique of the reliability of TL vs ^{14}C in the Southern Andes concluded that ^{14}C dates should be used in favor of TL dates to support cultural chronologies (Marsh et al. 2021) and discrepancies have also previously been noted regarding TL dates in Chile (Schiappacasse et al. 1991; Pavlovic et al. 2012). For these reasons, only the Aconcagua Valley ^{14}C dates were used in the KDEs produced for direct comparison with KDEs of the ^{14}C dates from EDQ.

These KDEs (Figure 6) indicate that the later phase of use observed at EDQ (start boundary *~cal AD 1344 (1320–1380, 68.3%)* to end *~cal AD 1441 (1430–1450, 68.3%)*), and indeed the burials identified with "*Local Inka Phase*" material culture (start boundary *~cal AD 1379 (1370–1400, 68.3%)* to end *~cal AD 1430 (1420–1440, 68.3%)*), fall just before the beginning of the known LP dates (start boundary *~cal AD 1457 (1420–1490, 68.3%)*) from the rest of the Aconcagua Valley and towards the end, or later than, the known LIP dates (end boundary *~cal AD 1399 (1330–1430, 68.3%)*) from the rest of the Valley.

The KDE for the "*Local Inka Phase*" material culture at EDQ indicates that Inka influence had arrived at this southern reach of the empire by the late 14th or early 15th century. The distribution of this KDE falls at the end boundary of the LIP dates for the Aconcagua Valley, and before the start boundary of other LP dates from the Aconcagua Valley. The "*Local Inka Phase*" material at EDQ likely represents the earlier stages of Inka influence in the Aconcagua Valley. The radiocarbon dates from the other known LP contexts, which

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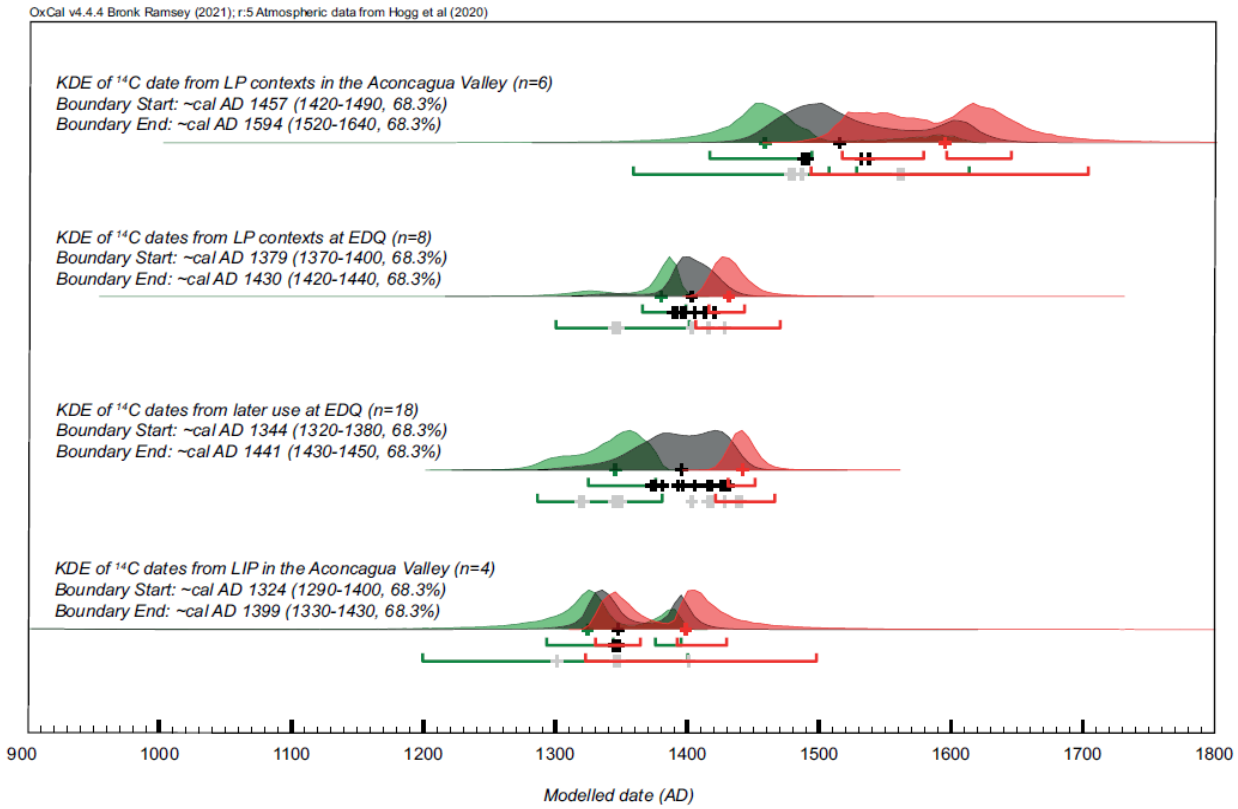


Figure 6 Kernel density estimates (KDEs) of the Estadio de Quillota radiocarbon dates from known Late Period contexts (upper middle) and the later use at EDQ (lower middle), compared to KDEs of radiocarbon dates from other Late Period (top) and Late Intermediate Period (bottom) sites or contexts in the Aconcagua Valley. The KDEs are presented in greyscale. The start and end boundaries for each KDE are represented in green and red, respectively (color version available online). Samples sizes of available radiocarbon dates for the Late Period (n=6) and Late Intermediate Period (n=4) in the Aconcagua are both very small, which has an effect of exaggerating the boundaries, and demonstrates a need for further radiometric dating in the region.

are located in the upper basin of the Aconcagua, are likely from a later stage of the imperial expansion in this region being from sites (El Tigre, Los Nogales, and Mt. Aconcagua) with a much more established physical Inka presence. Our findings agree with the recent assertions of Mundt and Marsh (2021) that the Aconcagua may have been an initial nucleus for the spread of Inka influence in Central Chile. However, our data indicates this initial phase was not confined just to the upper basin, but also present in the inland valley at EDQ on the midcourse of the Aconcagua River.

The earlier dates from "*Local Inka Phase*" contexts at EDQ suggest imperial expansion in this region followed a process of increasing influence and integration over time: an initial phase of interaction, visible through the circulation of ideas, influence, and material culture such as at EDQ, followed by a greater physical presence and occupation as seen at sites such as Mt Aconcagua and El Tigre. There are at least 10 other sites with Inka contexts in the Aconcagua Valley (see Figure 1), but as yet without any radiocarbon dating. Further efforts towards radiocarbon dating of Inka contexts in the Aconcagua Valley would make a beneficial contribution towards refining both the local Central Chilean chronology as well as the timing of Inka expansion towards their southern frontier.

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The new radiocarbon dates and chronometric models from EDQ presented here add to the growing evidence that Inka expansion commenced earlier than has been historically documented and provides a strong indication that Imperial influence had already arrived in Central Chile by at least ca. cal AD 1400. The early arrival of Inka influence in Central Chile has important implications, not just for the Empire's expansion into this region, but also supports an argument that the Imperial phase in Cuzco began earlier than AD 1438, and that the order of the expansion into the different quarters should be reconsidered. The EDQ Late Period model presented here predates the Bayesian model of Inka expansion for the neighbouring Mendoza province on the eastern side of the Andes (boundary start date *cal AD 1350–1440*) (Marsh et al. 2017). Both the model presented here for EDQ and the previous Marsh et al. (2017) model from Mendoza, collectively making up a considerable portion of the southern frontier of the Inka Empire, predate the Bayesian model from Chamical in southern Ecuador (boundary start date *cal AD 1412–1457*), which was part of *Chinchasusyu* and the northern quarter of the Empire (Ogburn 2012). In contrast to the sequence of Imperial expansion proposed by the traditional chronologies, a reinterpretation of Inka Imperial chronology based on these Bayesian models of radiometric dates suggests that the southern expansion of the Empire into *Collasuyu* probably took place before conquering parts of northern Peru and the more resistant and hostile regions of Ecuador in *Chinchasuyu*.

This new evidence has implications for understanding the nature of Inka control in these regions. The earlier radiometric dates seen from the southern frontier territory, such as the new dates from EDQ, possibly reflect the initial arrival of material culture and ideological influence of the Inka. This initial phase was then followed by an increased investment at a later stage in the Imperial rule, which saw the creation of a more substantial and visible physical presence, in the form of Inka structures, fortifications and an Inka *capacocha* child sacrifice on Mt Aconcagua. The results presented here support the hypothesis of Ogburn (2012) and Marsh *et al.* (2017) that the traditional chronology of the Inka Empire, including the sequence of expansion into the four regions of *Tawantinsuyu,* needs to be reconsidered, and can be usefully investigated with further efforts towards radiometric dating and Bayesian modeling of Inka contexts on the frontiers of the Empire.

CONCLUSION

The new radiocarbon dates presented here place the large pre-Columbian cemetery site of Estadio de Quillota within the chronology of the Aconcagua Valley, which was located on both the southern frontier of intensive maize agriculture and the Inka Empire. The AMS ^{14}C dates on human bone collagen from selected burials indicate that there were two distinct phases of use at EDQ separated by ca. 1000 years: An early phase from 339–196 cal BC to cal AD 128–339, roughly coincident with the Initial Ceramic Communities at the start of the Early Ceramic Period in Central Chile; and a late phase from cal AD 1280–1387 to cal AD 1413–1458 during which time Aconcagua, Diaguita, and Inka cultural influences are observed in the Valley.

The accompanying $\delta^{13}C$ and $\delta^{15}N$ stable isotopic analysis of the human bone collagen from 22 dated EDQ burials demonstrates a change in diet over time. The wide range of $\delta^{13}C$ values point towards a reliance on C_3 terrestrial resources during the earlier period of use, around the time of the Initial Ceramic Communities, followed by a heavy dependence on maize-based produce during the later phase of use observed at the EDQ cemetery. Due to the ca.

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1000-year gap, such that most of the Early Ceramic Period is unrepresented in the dates from EDQ, it is not possible to give a more precise estimation of when or how quickly this transition in diet and subsistence strategy occurred. However, the isotopic data presented here appear to follow a similar pattern to that which has been observed at sites further to the south where the use of maize was established at some point during the Early Ceramic Period, but more substantial uptake occurred in the Late Intermediate Period and marked intensification followed into the late 14th and early 15th centuries (Falabella et al. 2020), coincident with the findings from the later phase of use at EDQ.

Finally, the dates presented here support growing evidence that the traditional chronology of the Inka Empire, which has been based on historical documentary sources, requires reconsideration. Eight of the radiocarbon dates from the later phase of use at EDQ are from the bone collagen of individuals buried with ceramic items from the Late Period, many of a "*Local Inka Phase*" style indicative of a process of social transformations having already reached the region. These burials, however, predate the traditionally accepted date of Inka expansion to the south (AD 1471) as well as the date that has recently become more commonly used for the beginning of the Central Chilean Late Period (AD 1450). It is proposed that the expansion may have taken place in two phases: an initial phase of interaction including the circulation of ideas and the emerging influence of a new socio-political context, followed by a second phase of occupation with the construction of architectural complexes and consolidation of the region into the Empire. Bayesian modeling of the dates presented here supports a conclusion that Inka influence had arrived at its southern reaches by the late 14th or early 15th century, providing increasing evidence that the initial phase of Inka influence occurred several decades earlier than the date used traditionally. The findings presented here reinforce calls (cf. Ogburn 2012; Marsh et al. 2017) to abandon the traditional chronology based upon ethnohistoric sources and consider a major revision of Inka chronology with greater importance placed on evidence from radiometric dating.

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SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/RDC.2022.59

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Supplementary Material

Appendix A:
Compilation of previously published radiocarbon dates from pre-Columbian sites in the Aconcagua Valley

Lab Code	^{14}C yrs BP	Error	^{14}C yrs BC/AD	Site	Individual	Material	Setting	Reference
nr	*nr*	*nr*	470	Concon	nr	Shell	Coast	Ramírez (1989) in Seelenfreund and Westfall (2000)
nr	*nr*	100	420	Concon 11	nr	Shell	Coast	Carmona et al. (2001); Seelenfreund and Westfall (2000)
Beta-128761	6660	60	*nr*	S-Bato 1	Midden	Shell	Coast	Carmona et al. (2001); Seelenfreund and Westfall (2000)
Beta-128760	1560	40	*nr*	S-Bato 1	Hearth	Charcoal (wood)	Coast	Carmona et al. (2001); Seelenfreund and Westfall (2000)
Beta-210657	3810	40	*nr*	S-Bato 3	Area 2, Pozo 20, Nivel 28, Capa 4	Carbonised material	Coast	Carmona et al. (2001); Seelenfreund and Westfall (2000)
Beta-210658	2520	50	*nr*	S-Bato 3	Area 2, Perfil Capa 2, Base ocupacion 1	Shell	Coast	Carmona et al. (2001); Seelenfreund and Westfall (2000)
Beta-207406	1170	40	*nr*	S-Bato 3	Area 1, pozo sondeo 3, nivel 3	Shell	Coast	Carmona et al. (2001); Seelenfreund and Westfall (2000)
UGAMS30549	2650	50	-700	Plaza O'Higgins	2	Bone Collagen	Coast	Garceau (2017)
UGAMS30550	660	20	1290	Plaza O'Higgins	8	Bone Collagen	Coast	Garceau (2017)
UGAMS13205	630	20	*nr*	Estadio de Quillota	27-18	Bone Collagen	Inland Valley	Fuenzalida (2014)
UGAMS13207	620	20	*nr*	Estadio de Quillota	75-43	Bone Collagen	Inland Valley	Fuenzalida (2014)
UGAMS13209	570	20	*nr*	Estadio de Quillota	114-67	Bone Collagen	Inland Valley	Fuenzalida (2014)
UGAMS13206	540	20	*nr*	Estadio de Quillota	60-36	Bone Collagen	Inland Valley	Fuenzalida (2014)
UGAMS13210	540	20	*nr*	Estadio de Quillota	122-72	Bone Collagen	Inland Valley	Fuenzalida (2014)
UGAMS13208	520	20	*nr*	Estadio de Quillota	108-64	Bone Collagen	Inland Valley	Fuenzalida (2014)
nr	2830	110	*nr*	Las Chilcas 1	*nr*	Carbon	Upper Basin	Hermosilla (1994)
nr	1930	110	*nr*	Las Chilcas 1	*nr*	Carbon	Upper Basin	Hermosilla (1994)
nr	1380	120	*nr*	Las Chilcas 1	*nr*	Carbon	Upper Basin	Hermosilla (1994)
nr	1240	80	*nr*	Las Chilcas 1	*nr*	Carbon	Upper Basin	Hermosilla (1994)
nr	740	100	*nr*	Las Chilcas 1	*nr*	Carbon	Upper Basin	Biskupovic in Hermosilla (1994)
nr	460	70	*nr*	Las Chilcas 1	*nr*	Carbon	Upper Basin	Hermosilla (1994)

nr	4200	90	*nr*	Las Chilcas 2	*nr*	*nr*	Upper Basin	Hermosilla (1994)
nr	1810	90	*nr*	Las Chilcas 2	*nr*	*nr*	Upper Basin	Hermosilla (1994)
UGAMS 5982	620	25	*nr*	Los Nogales	*nr*	Charcoal	Upper Basin	Pavlovic (2010) in Plaza and Martinón-Torres (2015)
UGAMS 5976	600	20	*nr*	Los Nogales	*nr*	Bone (Human)	Upper Basin	Pavlovic (2010) in Plaza and Martinón-Torres (2015)
UGAMS 5979	430	25	*nr*	Los Nogales	*nr*	Bone (Camelid)	Upper Basin	Pavlovic (2010) in Plaza and Martinón-Torres (2015)
UGAMS 8278	340	30	*nr*	Los Nogales	*nr*	Bone (Camelid)	Upper Basin	Pavlovic (2010) in Plaza and Martinón-Torres (2015)
UGAMS 5530^	310	30	1640	El Tigre	*nr*	Charcoal	Upper Basin	Pavlovic, Troncoso, Sánchez, and Pascual (2012)
UGAMS 5531^	240	30	1710	El Tigre	*nr*	Charcoal	Upper Basin	Pavlovic et al. (2012)
UGAMS 5532	1100	30	850	El Tigre	*nr*	Ash	Upper Basin	Pavlovic et al. (2012)
UGAMS 5533^	270	40	1680	El Tigre	*nr*	Charcoal	Upper Basin	Pavlovic et al. (2012)
UGAMS 5980	340	25	1610	El Tigre	*nr*	Bone (Camelid)	Upper Basin	Pavlovic et al. (2012)
UGAMS 5981	370	30	1580	El Tigre	*nr*	Bone (Camelid)	Upper Basin	Pavlovic et al. (2012)
UGAMS 5983	440	25	1510	El Tigre	*nr*	Bone (Camelid)	Upper Basin	Pavlovic et al. (2012)
GX-19991-AMS	370	70	*nr*	Mt Aconcagua*	Aconcagua Boy Capacocha Sacrifice	Collagen (Bone)	Mountain	Fernández, Panarello, and Schobinger (1999)
Beta-88785	480	40	*nr*	Mt Aconcagua*	Aconcagua Boy Capacocha Sacrifice	Hair	Mountain	Marsh, Kidd, Ogburn, and Durán (2017)

nr = value not reported in the source

*Mt Aconcagua lies over the international border and in Argentina, however, as the Mountain sits above the Aconcagua Valley and headwaters of its eponymous river, the dates from this site have been included in this compilation along with the other dated sites from the Aconcagua Valley which lies within Central Chile.

^UGAMS 5531, 5532 and 5533 extend into the historic period and date burnt reed material from walls at the time of the destruction or abandonment of the El Tigre site (Pavlovic et al., 2021).

Compilation of previously published thermoluminescence dates from pre-Columbian sites in the Aconcagua Valley

Lab Code	TL yrs BP	Error	TL calendar years BC/AD	Year of Measure-ment	Site	Ind.	Material	Setting	Reference
nr	1485	150	465	*nr*	Calle 13	1	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1080	120	870	*nr*	El Membrillar I	3	Ceramic	Coast	Ávalos and Saunier (2011)
nr	470	55	1480	*nr*	El Membrillar I	*nr*	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1555	160	395	*nr*	El Membrillar II	*nr*	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1200	120	750	*nr*	El Membrillar II	*nr*	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1175	120	775	*nr*	El Membrillar II	*nr*	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1035	100	915	*nr*	El Membrillar II	*nr*	Ceramic	Coast	Ávalos and Saunier (2011)
nr	850	100	1100	*nr*	El Membrillar II	*nr*	Ceramic	Coast	Ávalos and Saunier (2011)
nr	805	90	1145	*nr*	El Membrillar II	*nr*	Ceramic	Coast	Ávalos and Saunier (2011)
nr	580	65	1370	*nr*	El Membrillar II	*nr*	Ceramic	Coast	Ávalos and Saunier (2011)
nr	515	45	1435	*nr*	El Membrillar II	*nr*	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1810	190	140	*nr*	Enap-3	1	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1755	180	195	*nr*	Enap-3	T-1: 0-10	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1625	170	325	*nr*	Enap-3	*nr*	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1610	170	340	*nr*	Enap-3	T-1: 50-60	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1470	160	480	*nr*	Enap-3	T-1: 30-50	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1470	150	480	*nr*	Enap-3	T-1: 60-70	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1410	150	540	*nr*	Enap-3	T-1: 70-80	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1240	130	710	*nr*	Enap-3	T-1: 20-30	Ceramic	Coast	Ávalos and Saunier (2011)

nr	1230	130	720	*nr*	Enap-3	T-1: 30-40	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1130	120	820	*nr*	Enap-3	T-1: 10-20	Ceramic	Coast	Ávalos and Saunier (2011)
UCTL-1331	1960	180	40	2000	Los Eucaliptos	*nr*	Ceramic	Coast	Carmona et al. (2001)
UCTL-1332	1820	200	180	2000	Los Eucaliptos	*nr*	Ceramic	Coast	Carmona et al. (2001)
UCTL-1329	1550	120	450	2000	Los Eucaliptus	unit 2	Ceramic	Coast	Carmona et al. (2001)
UCTL-1330	1500	100	500	2000	Los Eucaliptos	*nr*	Ceramic	Coast	Carmona et al. (2001)
UCTL-1334	1480	100	520	2000	Los Eucaliptos	*nr*	Ceramic	Coast	Carmona et al. (2001)
UCTL-1335	1420	100	580	2000	Los Eucaliptos	*nr*	Ceramic	Coast	Carmona et al. (2001)
UCTL-1333	1215	120	785	2000	Los Eucaliptos	*nr*	Ceramic	Coast	Carmona et al. (2001)
nr	1740	170	210	1998	Patio II	*nr*	Ceramic	Coast	Carmona et al. (2001)
nr	755	80	1195	*nr*	Patio II	*nr*	Ceramic	Coast	Ávalos and Saunier (2011)
nr	410	50	1540	*nr*	Cerro Mauco	*nr*	Ceramic	Coast	Ávalos and Saunier (2011)
nr	1375	140	575	*nr*	El Carrizo	1	Ceramic	Coast	Ávalos and Saunier (2011)
nr	565	50	1450	2015	Plaza O'Higgins	*nr*	Black-on-salmon ceramic	Coast	Garceau (2017)
nr	1810	150	140	*nr*	Aspillaga I	*nr*	Ceramic	Inland Valley	Ávalos and Strange in Carmona et al. (2001)
nr	910	100	1040	*nr*	Aspillaga I	*nr*	Ceramic	Inland Valley	Ávalos and Saunier (2011)
nr	1395	140	555	*nr*	Callle Santa Cruz	*nr*	Ceramic	Inland Valley	Ávalos and Strange in Carmona et al. (2001)
nr	580	65	1370	*nr*	Carolina	6 and 8	Ceramic	Inland Valley	Ávalos and Saunier (2011)
nr	450	50	1500	*nr*	Carolina	1	Ceramic	Inland Valley	Ávalos and Saunier (2011)
nr	1545	170	405	*nr*	EDQ	*nr*	Ceramic	Inland Valley	Ávalos and Saunier (2011)
nr	530	45	1420	*nr*	EDQ	*nr*	Ceramic	Inland Valley	Ávalos and Saunier (2011)
nr	1365	140	585	*nr*	Fundo Esmeralda	7	Ceramic	Inland Valley	Ávalos and Saunier (2011)
nr	970	105	980	*nr*	Fundo Esmeralda	1	Ceramic	Inland Valley	Ávalos and Saunier (2011)
nr	650	65	1300	*nr*	Fundo Esmeralda	9	Ceramic	Inland Valley	Ávalos and Saunier (2011)

nr	1270	100	680	*nr*	Calle Santa Rosa	*nr*	Ceramic	Inland Valley	Ávalos and Strange in Carmona et al. (2001)
UCTL 264	600	70	1390	1990	Cerro La Cruz	*nr*	Ceramic black/red on white	Upper Basin	Rodriguez et al. in Plaza and Martinón-Torres (2015)
UCTL 263	560	50	1430	1990	Cerro La Cruz	*nr*	Ceramic black/red on white	Upper Basin	Rodriguez et al. in Plaza and Martinón-Torres (2015)
UCTL 261	560	60	1430	1990	Cerro La Cruz	*nr*	Ceramic black on white	Upper Basin	Rodriguez et al. in Plaza and Martinón-Torres (2015)
UCTL 1020	955	80	1040	1995	Casa Blanca 1 "Ancuvina el Tartaro"	Tumba 3, Individuo 3, Pieza 3	Tipo Putaendo Rojo sobre Blanco	Upper Basin	Sánchez Romero (2000)
UCTL 1021	885	90	1110	1995	Casa Blanca 1 "Ancuvina el Tartaro"	Tumba 2, Individuo 6, Pieza 14	Tipo Putaendo Rojo Engobado	Upper Basin	Sánchez Romero (2000)
UCTL 1022	835	80	1160	1995	Casa Blanca 1 "Ancuvina el Tartaro"	Tumba 2, Individuo 2, Pieza 4	Tipo Putaendo Alisado (tonalidad: cafe)	Upper Basin	Sánchez Romero (2000)
UCTL 1103	1050	60	935	1995	Casa Blanca 10	Cuadricula 2, 20-30cm	Ceramic Café Alisado Ext./Int.	Upper Basin	Sánchez, Pavlovic, Gonzalez, and Troncoso (2004)
UCTL 1105	930	80	1065	1995	Casa Blanca 10	Unidad 2, nivel 2, 0-10cm	Tipo Putaendo Alisado (tonalidad: naranja)	Upper Basin	Sánchez et al. (2004)
UCTL 1102	805	60	1190	1995	Casa Blanca 10	Unidad 1, nivel 1, 0-10cm	Tipo Putaendo Rojo sobre Blanco	Upper Basin	Sánchez et al. (2004)
UCTL 1104	765	60	1230	1995	Casa Blanca 10	Unidad 1, nivel 2, 0-10cm	Tipo Putaendo Rojo Engobado	Upper Basin	Sánchez et al. (2004)
UCTL 1107	1115	70	880	1995	Casa Blanca 30	Cuadricula 2, 20-30cm	Ceramic Café Alisado Ext./Int.	Upper Basin	Sánchez et al. (2004)
UCTL 1106	430	59	1565	1995	Casa Blanca 30	Unidad 2, nivel 1, 0-10cm	Tipo Putaendo Rojo sobre Blanco	Upper Basin	Sánchez et al. (2004)
UCTL 1395	*nr*	70	1230	2002	Casa Blanca 36	Recoleccion Superficial	Tipo Putaendo Rojo sobre Blanco	Upper Basin	Pavlovic (2006)

UCTL 962	945	100	1050	1995	Cementerio Bellavista A	Tumulo Z, Individuo 13, 40cm	Café alisado ext./int.	Upper Basin	Sánchez Romero (2000)
UCTL 963	910	90	1085	1995	Cementerio Bellavista A	Tumulo B, Individuo 2, 40-60cm	Café alisado ext./int.	Upper Basin	Sánchez Romero (2000)
UCTL 964	915	100	1080	1995	Cementerio Bellavista A	Tumulo X, Individuo 11, 65-75cm	Café alisado ext./int.	Upper Basin	Sánchez Romero (2000)
UCTL 1165	540	60	1455	1995	Cementerio El Palomar	*nr*	Ceramic Puco T.A. Tricromo Engobado. Registro MHN 11.848	Upper Basin	Sánchez et al. (2004)
UCTL 1166	800	80	1195	1995	Cementerio El Palomar	*nr*	Ceramic Puco T.A. Negro sobre Salmon (Trinacrio Exterior). Registro MHN 3.899/5.258	Upper Basin	Sánchez et al. (2004)
UCTL 1167	1055	110	940	1995	Cementerio El Palomar	*nr*	Ceramic Puco T.A. Negro sobre Salmon (Trinacrio Exterior). Registro MHN 3.899/5.258	Upper Basin	Sánchez et al. (2004)
UCTL 1168	1125	120	870	1995	Cementerio El Palomar	*nr*	Ceramic Puco T.A. Negro sobre Salmon (Trinacrio Exterior). Registro MHN 3.899/5.258	Upper Basin	Sánchez et al. (2004)
UCTL 1405	610	60	1390	*nr*	Cerro Mercachas	Pozo 4	Blanco y negro sobre rojo ext./Alisado Tosco Int.	Upper Basin	Sánchez Romero (2001)
UCTL 1406	525	50	1475	*nr*	Cerro Mercachas	Pozo 4, 15-20cm	Blanco y negro sobre rojo ext./Alisado Escobillado Int.	Upper Basin	Sánchez Romero (2001)

UCTL 1407	350	30	1650	*nr*	Cerro Mercachas	Pozo 3, 0-5cm	Café Claro Pulido Ext./Café Pulido Int.	Upper Basin	Sánchez Romero (2001)
UCTL 1243	485	50	1515	*nr*	El Castillo	Caudricula 1, 10-20cm	Plato playo (rojo ext/negro sobre rojo int decoracion: Linea horizontal bajo el borde	Upper Basin	Sánchez Romero (2001)
UCTL 1244	590	60	1410	*nr*	El Castillo	Caudricula 1, 10-20cm	Aribalo (alisado int./negro y rojo sobre blanco ext decoracion: Bastones hileras)	Upper Basin	Sánchez Romero (2001)
UCTL 1245	615	60	1385	*nr*	El Castillo	Caudricula 1, 10-20cm	Escudilla Diaguita II (Negro y Rojo sobre Blanco ext./blanco int. decoracion: Patron zig-zag)	Upper Basin	Sánchez Romero (2001)
UCTL 1246	600	60	1400	*nr*	El Castillo	Cuadricula 1, 20-30cm	Aribalo (Negro sobre blanco ext./Alisado Int. Decoracion: Lineal)	Upper Basin	Sánchez Romero (2001)
UCTL 1392	*nr*	70	1260	2002	El Tartaro 12	Recoleccion Superficial	Rojo Engobado exterior / Rojo y negro sobre Blanco interior	Upper Basin	Pavlovic (2006)
UCTL 1393	*nr*	60	1345	2002	El Tartaro 14	Recoleccion Superficial	Rojo Engobado exterior / Rojo y negro sobre rojo interior	Upper Basin	Pavlovic (2006)
UCTL 1394	*nr*	80	1170	2002	El Tartaro 15	Recoleccion Superficial	Tipo Putaendo Rojo sobre Blanco	Upper Basin	Pavlovic (2006)
UCTL 1256	960	90	1040	2000	Pocuro 2 "Los Rosales 1"	Recoleccion Superficial	Ceramic T.A. Negro sobre salmon	Upper Basin	Sánchez et al. (2004)
UCTL 1257	980	100	1020	2000	Pocuro 2 "Los Rosales 1"	Caudricula 2, 60-70cm	Ceramic Rojo engobado	Upper Basin	Sánchez et al. (2004)

							ext. negro ahumado int. (var. decorada)		
UCTL 1258	1060	90	940	2000	Pocuro 2 "Los Rosales 1"	Caudricula 2, 60-70cm	Café alisado ext./int.	Upper Basin	Sánchez et al. (2004)
UCTL 1259	1050	100	950	2000	Pocuro 2 "Los Rosales 1"	Caudricula 2, 70-80cm	Ceramic T.A. Negro sobre salmon	Upper Basin	Sánchez et al. (2004)
UCTL 1261	930	60	1070	2000	Pocuro 4 "Los Rosales 2"	Cuadricula 2, 40-50cm	Ceramic T.A. Negro sobre salmon	Upper Basin	Sánchez et al. (2004)
UCTL 1260	680	70	1320	2000	Pocuro 4 "Los Rosales 2"	Cuadricula 2, 40-50cm	Ceramic Care Alisado ext./int.	Upper Basin	Sánchez et al. (2004)
UCTL 1247	665	70	1335	2000	Pocuro 4 "Los Rosales 2"	Contexto Funerario 3, Tumba 2	Ceramic Rojo engobado ext. café pulido int. (var. decorada)	Upper Basin	Sánchez et al. (2004)
UCTL 1248	875	90	1125	2000	Pocuro 8 "El Sauce"	tumba 2, Individuos 2 y 3	Ceramic Café Alisado Ext./Int.	Upper Basin	Sánchez et al. (2004)
UCTL 1255	500	40	1500	2000	Pucara El Tartaro	Cuadricula 2, 0-10cm	Escudilla Diaguita (Rojo Egobado Ext./Blanco Int.)	Upper Basin	Sánchez Romero (2001)
UCTL 1254	480	50	1520	2000	Pucara El Tartaro	Recoleccion Superficial	Escudilla Diaguita (Rojo Egobado Ext./Blanco Int.)	Upper Basin	Sánchez Romero (2001)
UCTL 1250	630	50	1370	2000	Pucara El Tartaro	Recoleccion Superficial	Rojo Engobado Ext./Café Rojizo Alisado Int.	Upper Basin	Sánchez Romero (2001)
UCTL 1252	555	60	1445	2000	Pucara El Tartaro	Recoleccion Superficial	Negro sobre Blanco Ext./Blanco Int. Decoracion: Motivo Subrectangular de bordes curvos	Upper Basin	Sánchez Romero (2001)
UCTL 1253	640	60	1360	2000	Pucara El Tartaro	Recoleccion Superficial	Escudilla Diaguita III (Negro y Blanco sobre Rojo Ext./Blanco Int.) Decoracio	Upper Basin	Sánchez Romero (2001)

UCTL 1249	600	50	1400	2000	Pucara El Tartaro	Recolection Superficial	n: Patron Ondas T.A Negro sobre salmon decoracion: Lineal	Upper Basin	Sánchez Romero (2001)
UCTL 1251	420	40	1580	2000	Pucara El Tartaro	Recolection Superficial	Rojo sobre blanco ext./café rojizo alisado Int. Decoracion: Lineal (estrellado)	Upper Basin	Sánchez Romero (2001)
UCTL 1690	*nr*	85	1170	2006	Ramadillas 1 "La Higuera"	Pozo 2, nivel 2, 10-12cm	Tipo Putaendo Alisado	Upper Basin	Troncoso (2006)
UCTL 1689	*nr*	60	1245	2006	Ramadillas 1 "La Higuera"	Pozo 1, nivel 2, 10-20cm	Tipo Putaendo Rojo Engobado	Upper Basin	Troncoso (2006)
UCTL 1241	1075	80	925	*nr*	Los Patos 6	Cuadricula 1, 10-20cm	Rojo Engobado Fino ext./Alisado int.	Upper Basin	Pavlovic (2000)
UCTL 1242	1010	100	990	*nr*	Los Patos 6	Cuadricula 1, 20-30cm	Café alisado ext./int.	Upper Basin	Pavlovic (2000)
UCTL 1134	1395	80	600	*nr*	La Nogalada	Cuadricula 1, 10-20cm	Negro pulido ext. / Alisado int.	Upper Basin	Pavlovic (2000)
UCTL 1111	805	60	1190	*nr*	Parco El Ingenio	Cuadricula D, 0-10cm	Negro pulido ext. / Alisado int.	Upper Basin	Pavlovic (2000)
UCTL 1687	595	70	1355	*nr*	El Tigre		Ceramic	Upper Basin	Pavlovic et al. (2012)
UCTL 1688	725	80	1225	*nr*	El Tigre		Ceramic	Upper Basin	Pavlovic et al. (2012)

nr = value not reported in the source

Calibrated and modelled radiocarbon and thermoluminescence dates from pre-Columbian Aconcagua Valley sites

Sample/Lab Code	Unmodelled (BC/AD)			Modelled (BC/AD)		
	from	to	median	from	to	median
Curve SHCal20						
Boundary Start				-5678	-5377	-5525
R_Date Beta-128761, S-Bato 1	-5661	-5474	-5558	-5616	-5367	-5491
R_Date Beta-210657, S-Bato 3	-2397	-2034	-2197	-2397	-2034	-2197
R_Date Las Chilcas 1	-1278	-776	-978	-1278	-777	-978
R_Date Plaza O'Higgins Ind2	-905	-547	-791	-906	-547	-791
R_Date Beta-210658, S-Bato 3	-776	-416	-616	-776	-416	-616
R_Date OxA V-2735-19 EDQ	-399	-196	-273	-399	-196	-273
R_Date OxA V-2735-13 EDQ	-365	-70	-190	-366	-71	-191
R_Date OxA V-2730-57 EDQ	-146	22	-71	-146	22	-71
R_Date Las Chilcas 1	-140	381	124	-140	377	124
R_Date Las Chilcas 2	30	520	265	29	518	265
C_Date UCTL 1331, Los Eucaliptos	-322	400	40	-326	400	40
R_Date OxA V-2737-44 EDQ	128	339	232	128	339	233
C_Date Aspillaga I	-162	440	140	-165	438	140
C_Date UCTL 1332, Los Eucaliptos	-222	580	180	-220	583	179
C_Date ENAP-3	-242	520	140	-243	518	140
C_Date ENAP-3	-167	555	195	-166	556	195
C_Date Patio II	-132	550	210	-133	548	210
C_Date ENAP-3	-17	665	325	-16	670	325
C_Date ENAP-3	-2	680	340	-2	680	340
C_Date ENAP-3	-17	665	325	-16	667	325
C_Date ENAP-3	-2	680	340	2	681	340
R_Date Beta-128760, S-Bato 1	435	636	551	435	636	551
C_Date El Membrillar II	75	715	395	72	716	394
C_Date EDQ	65	745	405	64	748	405
C_Date Concon 11	220	620	420	220	620	420
C_Date UCTL 1329, Los Eucaliptos	210	690	450	211	694	450
C_Date Calle 13	165	765	465	159	764	465
C_Date Concon	270	670	470	269	672	470
C_Date ENAP-3	160	800	480	160	803	479
C_Date ENAP-3	180	780	480	181	780	480
C_Date UCTL 1330, Los Eucaliptos	300	700	500	300	700	500
C_Date UCTL 1334, Los Eucaliptos	320	720	520	320	720	519
C_Date ENAP-3	240	840	540	237	845	540
C_Date Calle Santa Cruz	275	835	555	276	839	555
C_Date El Carrizo	295	855	575	293	855	575

C_Date UCTL 1335, Los Eucaliptos	380	780	580	378	779	580
C_Date Fundo Esmeralda	305	865	585	305	865	585
R_Date Las Chilcas 1	441	987	717	440	984	717
C_Date Santa Rosa	480	880	680	480	880	679
C_Date UCTL 1134, La Nogalada	440	760	600	439	759	600
R_Date Las Chilcas 1	676	992	840	676	992	839
C_Date ENAP-3	450	970	710	453	970	710
C_Date ENAP-3	460	980	720	460	980	720
C_Date UCTL 1333, Los Eucaliptos	545	1025	785	543	1022	785
C_Date El Membrillar II	510	990	750	509	989	750
C_Date El Membrillar II	535	1015	775	534	1015	775
R_Date Beta-207406, S-Bato 3	773	1018	931	773	1017	931
C_Date UCTL 1111, Parco El Ingenio	685	925	805	685	926	805
C_Date ENAP-3	580	1060	820	579	1059	820
C_Date El Membrillar I	630	1110	870	631	1113	870
C_Date UCTL 1168 Cementerio El Palomar	630	1110	870	629	1110	870
C_Date UCTL 1107 Casa Blanca 30	740	1020	880	740	1021	880
C_Date El Membrillar II	715	1115	915	716	1115	914
C_Date UCTL 1241, Los Patos	785	1065	925	784	1065	925
C_Date UCTL 1103 Casa Blanca 10	815	1055	935	814	1054	935
C_Date UCTL 1258 Pocuro 2	760	1120	940	758	1119	940
C_Date UCTL 1167 Pocure 2	720	1160	940	720	1161	940
C_Date UCTL 1259 Los Rosales 1	750	1150	950	750	1151	950
C_Date Fundo Esmeralda	780	1180	980	779	1180	980
C_Date UCTL 1242, Los Patos	790	1190	990	791	1194	990
C_Date UCTL 1257 Los Rosales 1	820	1220	1020	819	1220	1020
C_Date Aspillaga I	840	1240	1040	840	1241	1040
C_Date UCTL 1256 Los Rosales 1	860	1220	1040	860	1220	1040
C_Date UCTL1020 Ancuvina el Tartaro	880	1200	1040	878	1199	1040
C_Date UCTL 962 Cementerio Bellavista A	850	1250	1050	850	1251	1050
C_Date UCTL 1105 Casa Blanca 10	905	1225	1065	903	1224	1065
C_Date UCTL 1261 Los Rosales 2	950	1190	1070	949	1189	1070
C_Date UCTL 964 Cementerio Bellavista A	880	1280	1080	880	1280	1080
C_Date UCTL 963 Cementerio Bellavista A	905	1265	1085	904	1263	1084
C_Date El Membrillar II	900	1300	1100	899	1299	1100
C_Date UCTL 1021 Ancuvina el Tartaro	930	1290	1110	930	1290	1110
C_Date UCTL 1248 El Sauce	945	1305	1125	944	1304	1125
C_Date El Membrillar II	965	1325	1145	965	1325	1145
C_Date UCTL 1022 Ancuvina el Tartaro	1000	1320	1160	1000	1320	1160
C_Date UCTL 1394 El Tartaro 15	1010	1330	1170	1010	1331	1170
C_Date UCTL 1690 La Higuera	1000	1340	1170	1000	1340	1170
C_Date UCTL 1102 Casa Blanca 10	1070	1310	1190	1070	1310	1189
C_Date UCTL 1166 Cementerio El Palomar	1035	1355	1195	1034	1355	1195

C_Date Patio II	1035	1355	1195	1035	1356	1195
R_Date Las Chilcas 1	1073	1437	1301	1073	1438	1301
C_Date UCTL 1688 El Tigre	1065	1385	1225	1065	1385	1225
C_Date UCTL 1104 Casa Blanca 10	1110	1350	1230	1110	1350	1230
C_Date UCTL 1395 Casa Blanca 36	1090	1370	1230	1089	1369	1229
C_Date UCTL 1689 La Higuera	1125	1365	1245	1125	1366	1245
C_Date UCTL 1392 El Tartaro 12	1120	1400	1260	1119	1399	1260
R_Date OxA V-2730-55 EDQ	1280	1387	1318	1280	1388	1318
R_Date OxA V-2735-12 EDQ	1278	1389	1320	1278	1390	1320
R_Date OxA V-2735-9 EDQ	1285	1392	1349	1285	1392	1349
R_Date OxA V-2735-16 EDQ	1287	1394	1348	1287	1394	1348
R_Date OxA V-2735-15 EDQ	1288	1394	1348	1288	1394	1348
R_Date OxA V-2735-14 EDQ	1296	1396	1346	1296	1396	1346
R_Date OxA V-2737-43 EDQ	1297	1395	1346	1297	1395	1347
R_Date Plaza O'Higgins Ind8	1300	1399	1345	1300	1399	1345
R_Date OxA V-2735-10 EDQ	1297	1403	1345	1297	1402	1345
C_Date Fundo Esmeralda	1170	1430	1300	1170	1430	1300
R_Date UGAMS13205 EDQ	1318	1408	1343	1318	1408	1344
R_Date UGAMS13207 EDQ	1320	1413	1347	1319	1413	1347
C_Date UCTL 1260 Pocuro 4	1180	1460	1320	1180	1460	1320
R_Date UGAMS 5982 Los Nogales	1318	1415	1348	1317	1416	1349
R_Date UGAMS 5976 Los Nogales	1323	1423	1401	1323	1423	1401
C_Date UCTL 1247 Pocuro 4	1195	1475	1335	1195	1475	1335
C_Date UCTL 1393 El Tartaro 14	1225	1465	1345	1224	1465	1345
C_Date UCTL 1687 El Tigre	1215	1495	1355	1214	1494	1355
C_Date UCTL 1253 Pucara El Tartaro	1240	1480	1360	1239	1480	1360
C_Date El Membrillar II	1240	1500	1370	1239	1500	1370
C_Date Carolina	1240	1500	1370	1240	1500	1370
R_Date OxA V-2735-17 EDQ	1328	1444	1415	1328	1445	1415
C_Date UCTL 1250 Pucara El Tartaro	1270	1470	1370	1270	1470	1370
C_Date UCTL 1245 El Castillo	1265	1505	1385	1264	1504	1385
C_Date UCTL 264 Cerro La Cruz	1250	1530	1390	1250	1530	1389
C_Date UCTL 1405 Cerro Mercachas	1270	1510	1390	1270	1511	1390
R_Date UGAMS13209 EDQ	1396	1439	1415	1395	1439	1415
R_Date OxA V-2742-15 EDQ	1395	1446	1418	1395	1446	1418
R_Combine OxA V-2730-53&54	1324	1425	1402	1324	1424	1403
C_Date UCTL 1246 El Castillo	1280	1520	1400	1280	1520	1400
C_Date UCTL 1249 Pucara El Castillo	1300	1500	1400	1299	1499	1400
C_Date UCTL 1244 El Castillo	1290	1530	1410	1290	1530	1410
R_Date UGAMS13206 EDQ	1407	1446	1427	1408	1446	1428
R_Date UGAMS13210 EDQ	1407	1446	1427	1408	1446	1427
C_Date EDQ	1330	1510	1420	1330	1510	1420
C_Date UCTL 263 Cerro La Cruz	1330	1530	1430	1329	1529	1430

C_Date UCTL 261 Cerro La Cruz	1310	1550	1430	1309	1549	1430
C_Date El Membrillar II	1345	1525	1435	1344	1525	1435
C_Date UCTL 1252 Pucara El Tartaro	1325	1565	1445	1325	1565	1445
C_Date UCTL 1165 Cementerio El Palomar	1335	1575	1455	1335	1573	1455
R_Date OxA V-2730-56 EDQ	1411	1455	1437	1411	1455	1436
R_Date OxA V-2735-18 EDQ	1413	1458	1439	1413	1458	1439
C_Date El Membrillar I	1370	1590	1480	1370	1586	1479
R_Date Las Chilcas 1	1405	1632	1491	1405	1626	1487
R_Date UGAMS 5983 El Tigre	1445	1619	1479	1445	1618	1478
C_Date Plaza O'Higgins	1350	1550	1450	1350	1550	1450
C_Date UCTL 1406 Cerro Mercachas	1375	1575	1475	1374	1574	1475
C_Date Carolina	1400	1600	1500	1400	1596	1499
C_Date UCTL 1255 Pucara El Tartaro	1420	1580	1500	1419	1579	1500
C_Date UCTL 1243 El Castillo	1415	1615	1515	1415	1610	1514
C_Date UCTL 1254 Pucara El Tartaro	1420	1620	1520	1420	1613	1519
R_Date UGAMS 5979 Los Nogales	1446	1623	1485	1446	1622	1484
R_Combine GX-19991-AMS + Beta-88785 Mt Aconcagua	1426	1623	1476	1426	1622	1475
C_Date Cerro Mauco	1440	1640	1540	1440	1629	1537
R_Date UGAMS 5981 El Tigre	1463	1636	1559	1464	1631	1554
R_Date UGAMS 8278 Los Nogales	1497	1653	1562	1490	1649	1554
R_Date UGAMS 5980 El Tigre	1501	1649	1561	1501	1646	1553
C_Date UCTL 1106 Casa Blanca 30	1446	1683	1565	1446	1652	1555
Boundary End				1565	1768	1647

Appendix B:

OxCal Code for KDE Plot of Late Period Sites in the Aconcagua Valley

```
Plot()
 {
  Curve("SHCal20","SHCal20.14c");
  Sequence()
  {
   Boundary(Start LP Aconcagua Valley 14C Only)
   {
    color="green";
   };
   KDE_Plot("LP Aconcagua Valley 14C Only")
   {
    R_Date("UGAMS 5983 El Tigre", 440, 25);
    R_Date("UGAMS 5979 Los Nogales", 430, 25);
    R_Combine("GX-19991-AMS + Beta-88785 Mt Aconcagua")
    {
     R_Date("GX-19991-AMS Mt Aconcagua", 370, 70);
     R_Date("Beta-88785 Mt Aconcagua", 480, 40);
    };
    R_Date("UGAMS 5981 El Tigre", 370, 30);
    R_Date("UGAMS 8278 Los Nogales", 340, 30);
    R_Date("UGAMS 5980 El Tigre", 340, 25);
   };
   Boundary(End LP Aconcagua Valley 14C Only)
   {
    color="red";
   };
  };
};
```

OxCal Code for KDE Plot of Estadio de Quillota Late Period Contexts

```
Plot()
 {
  Curve("SHCal20","SHCal20.14c");
  Sequence()
  {
   Boundary(Start EDQ Known LP Contexts Only)
   {
    color="green";
   };
   KDE_Plot("EDQ Known LP Contexts Only")
   {
    R_Date("OxA V-2735-14 EDQ", 672, 27);
    R_Date("OxA V-2735-10 EDQ", 657, 29);
    R_Date("UGAMS13205 EDQ", 630, 20);
    R_Date("UGAMS13207 EDQ", 620, 20);
    R_Date("UGAMS13209 EDQ", 570, 20);
    R_Combine("OxA V-2730-53&54")
    {
     R_Date("EDQ16077", 579, 25);
     R_Date("EDQ16077", 614, 25);
    };
    R_Date("UGAMS13206 EDQ", 540, 20);
    R_Date("UGAMS13210 EDQ", 540, 20);
   };
   Boundary(End EDQ Known LP Contexts Only)
   {
    color="red";
   };
  };
};
```

OxCal Code for KDE Plot of Estadio de Quillota Later Phase of Use

```
Plot()
 {
  Curve("SHCal20","SHCal20.14c");
  Sequence()
  {
   Boundary(Start EDQ Later Use);
   KDE_Plot("EDQ Later Use")
   {
    R_Date("OxA V-2730-55 EDQ", 722, 25);
    R_Date("OxA V-2735-12 EDQ", 721, 29);
    R_Date("OxA V-2735-9 EDQ", 702, 26);
    R_Date("OxA V-2735-16 EDQ", 693, 28);
    R_Date("OxA V-2735-15 EDQ", 690, 28);
    R_Date("OxA V-2735-14 EDQ", 672, 27);
    R_Date("OxA V-2737-43 EDQ", 672, 25);
    R_Date("OxA V-2735-10 EDQ", 657, 29);
    R_Date("UGAMS13205 EDQ", 630, 20);
    R_Date("UGAMS13207 EDQ", 620, 20);
    R_Date("OxA V-2735-17 EDQ", 570, 27);
    R_Date("UGAMS13209 EDQ", 570, 20);
    R_Date("OxA V-2742-15 EDQ", 562, 27);
    R_Combine("OxA V-2730-53&54")
    {
     R_Date("EDQ16077", 579, 25);
     R_Date("EDQ16077", 614, 25);
    };
    R_Date("UGAMS13206 EDQ", 540, 20);
    R_Date("UGAMS13210 EDQ", 540, 20);
    R_Date("OxA V-2730-56 EDQ", 515, 26);
    R_Date("OxA V-2735-18 EDQ", 507, 27);
   };
   Boundary(End EDQ Later Use);
  };
 };
```

OxCal Code for KDE Plot of Late Intermediate Period Sites in the Aconcagua Valley

```
Plot()
 {
  Curve("SHCal20","SHCal20.14c");
  Sequence()
  {
   Boundary(Start LIP Aconcagua Valley 14C Only)
   {
    color="green";
   };
   KDE_Plot("LIP Aconcagua Valley 14C Only")
   {
    R_Date("Las Chilcas 1", 740, 100);
    R_Date("Plaza O'Higgins Ind8", 660, 20);
    R_Date("UGAMS 5982 Los Nogales", 620, 25);
    R_Date("UGAMS 5976 Los Nogales", 600, 20);
    R_Date("Las Chilcas 1", 460, 70);
   };
   Boundary(End LIP Aconcagua Valley 14C Only)
   {
    color="red";
   };
  };
 };
```

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CHAPTER 4: THE FRONTIER OF MAIZE AGRICULTURE: STABLE ISOTOPE EVIDENCE OF PRE-COLUMBIAN DIETARY SHIFTS IN THE ACONCAGUA AND LA LIGUA VALLEYS OF CENTRAL CHILE

1. Introduction

The adoption and intensification of agriculture precipitated far-reaching changes in human diet and health. The appearance of maize in the archaeological record of the Americas is an important indicator of agricultural expansion and often concomitant with social and political developments. The Southern Andes of Argentina and Chile, incorporating Central Chile, make up the southern frontier of maize agriculture in the Americas. Much of the research from this area has focused on Central Western Argentina, and the Maipo-Mapocho and Cachapoal river valley systems surrounding Santiago in Central Chile. However, there has been little investigation of dietary and subsistence patterns practiced by the pre-Columbian inhabitants in the vast Central Chilean area that is incorporated by the Aconcagua and La Ligua river valleys.

Building on prior regional isotopic studies (Falabella and Sanhueza 2019; Falabella et al. 2020; Swift et al. 2017; Tykot et al. 2009), this work further investigates the timing and nature of maize adoption in the Aconcagua and La Ligua valleys to address gaps in understanding regional variability and the social implications of maize use in these frontier zones. The introduction and intensification of maize as a staple resource in the Aconcagua and La Ligua river valleys of Central Chile is examined using stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopic analyses of human bone collagen. The study encompasses multiple cemetery sites along the courses of both valleys (Figure 1), spanning the Early Ceramic Period through the Late Intermediate and to the Late Period (c. 300 cal BC - cal AD 1532), representing the initial transition to, and subsequent intensification of, maize agriculture and the later expansion of Inka imperial influence (Table 1).

The aim of this study is to examine dietary changes over time, with particular reference to the incorporation of maize. Variations in diet between coastal and inland settings, as well as multiple cultural settings, are assessed to examine when and among which groups maize was first incorporated into the diet and whether the transition and subsequent intensification of maize agriculture was a rapid or gradual process. This paper also seeks to identify changes in the economic significance of maize, examining whether it served solely as a dietary staple or also had potential social significance, such as ritual or luxury roles, particularly in relation to sex-based dietary access.

2. Background

The Southern Andes (Central Western Argentina and Central Chile) was home to some of the southernmost agriculturalists of South America, and the final region to adopt cultivation in pre-Hispanic times (Gil 2003). The role of maize in Andean societies is complex and regionally variable (Barberena et al. 2023; Tessone et al. 2024) and in many parts of the Andes intensification of maize agriculture is linked with increasing social complexity (Finucane et al. 2006; Hastorf and Johannessen 1993; Tung and Knudson 2018; van der Merwe et al. 1993).

While the transition to maize farming is an enduring topic of inquiry in American archaeology, previous research in Central Chile, including isotopic studies, has concentrated on the Maipo-Mapocho basin around Santiago and the Cachapoal river to the south, with scant focus on the Central Chilean Aconcagua and La Ligua Valleys to the north of Santiago (Falabella et al. 2016b). Some preliminary stable isotopic data from the Aconcagua Valley (n=24) has indicated a wide range in $\delta^{13}C$ values (-20.4‰ to -11.4‰) and pointed to an increasing inclusion of maize in the diet over time, particularly from the Late Intermediate Period (ca. AD 1000/1200) onwards (Swift et al. 2017). However, beyond these initial indications, patterns of maize use remain largely unknown in the Aconcagua and La Ligua Valleys.

Most bioarchaeological research has focused on the South Central Andes, including the arid regions in the north of the country, where subsistence strategies were governed by the extremely harsh environmental conditions of the Atacama Desert (Alfonso-Durruty et al. 2019; Allison 1984; Pestle et al. 2021; Roberts et al. 2013; Santana-Sagredo et al. 2015a; Santana-Sagredo et al. 2021). Central Chile, on the other hand, has had a milder, Mediterranean-type climate for at least the past 3,000 years (Jenny et al. 2002; Villa-Martínez et al. 2003; Villagrán and Varela 1990), with fertile river valleys ideally suited for large-scale maize farming. Chroniclers from the post-contact period described the Aconcagua Valley in particular as an epicenter for the production of maize, "famous for the prodigious quantity of corn carried from it yearly" (Frézier 1717, p.116).

Age	Temporal Period	Cultural Phases
> ca. 10,000 BC	Terminal Pleistocene	Palaeoindian
ca. 10,000–300 BC	Archaic	Archaic Phases I, II, II & IV
ca. 400 BC–AD 1000/1200	Early Ceramic (ECP)	Initial Ceramic Communities (ca. 400 BC–AD 200) Bato (ca. AD 200–1000) Llolleo (ca. AD 400–1200)
ca. AD 1000/1200–1350/1450	Late Intermediate (LIP)	Aconcagua
ca. AD 1350/1450–1536	Late (LP)	Aconcagua Diaguita-Inka

Table 1: *Summary of archaeological periods and cultural phases relevant to the Aconcagua and La Ligua river valleys of Central Chile (adapted from Falabella et al. (2016b) and (Swift et al. 2022)).*

Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analyses have been increasingly applied in archaeological contexts to reconstruct diet and infer prehistoric subsistence strategies. Differences in $\delta^{13}C$ and $\delta^{15}N$ can be useful for distinguishing between diets reliant upon different types of plant resources, as well as between marine, terrestrial and sometimes freshwater ecosystems (Schoeninger and DeNiro 1984).

Stable carbon isotopes can distinguish between some types of terrestrial resources based on different photosynthetic pathways used by plants (mainly C_3 vs. C_4). Vegetation in temperate zones generally follows a C_3 photosynthetic pathway, as does much of the native vegetation from Central Chile (Planella et al. 2014; Planella and Tagle 2004; Planella 2005; Rossen et al. 2010). Certain important cultigens, including maize, follow the C_4 photosynthetic pathway. Stable carbon isotope values for C_3 vegetation generally average around -26.5‰, whereas C_4 plants have values around -12.5‰ (Smith and Epstein 1971). Given this clear separation, $\delta^{13}C$ is particularly useful for detecting the introduction and intensification of maize in prehistoric human diets. In southern Peru, a number of other edible C_4 plants have been identified from the *Graminae, Cheopodiaceae, Asteraceae* and *Amaranthaceae* families (Cadwallader et al. 2012). Hence, the possibility of C_4 plants other than maize contributing to elevated $\delta^{13}C$ values in humans cannot be entirely excluded, however, there is no suggestion or archaeobotanical evidence of use of C_4 plants apart from *Zea mays* in Central Chile (Belmar et al. 2013; Planella et al. 2014; Planella et al. 2013; Planella and Tagle 2004; Planella Ortíz 2019; Rossen et al. 2010; Sanhueza et al. 2003).

There is a fractionation between the isotopic values of plants and the body tissues of the animals that consume them, due to metabolic processes. There is a shift of about +5‰ from the $\delta^{13}C$ values of the resource to the $\delta^{13}C$ values observed in bone collagen of the consumer ($\Delta^{13}C_{diet\text{-}collagen}$) (Ambrose and Norr 1993; Tieszen and Fagre 1993). This includes a trophic level shift of ca. +1‰ for $\delta^{13}C$, which also occurs for each subsequent step in the food chain (Bocherens and Drucker 2003). Modern plants also require a correction of ca. +1.5‰ when compared with archaeological material due to the Suess Effect, a depletion in atmospheric $\delta^{13}C$ values as a result of admixture with industrial carbon dioxide (Keeling 1979).

Stable nitrogen isotopes provide information about trophic level, with an increase of about 3-5‰ for each step up the food chain (Hedges and Reynard 2007; Schoeninger and DeNiro 1984). As there are many more trophic levels in the marine food chain, compared to terrestrial food chains, consumers of marine resources often can be distinguished by higher $\delta^{15}N$ values. For example, populations from coastal northern Chile

known to be heavily reliant on high-trophic-level marine foods have been reported with $\delta^{15}N$ as high as 17.3 to 26.7‰ (Roberts et al. 2013; Santana-Sagredo et al. 2021).

There are other factors, apart from trophic level, that can also elevate $\delta^{15}N$ in food resources, such as aridity (Pate and Anson 2008) and manuring crops (Bogaard et al. 2013; Santana-Sagredo et al. 2021; Szpak et al. 2012). Conversely, nitrogen-fixing plants, which includes most legumes, have depleted $\delta^{15}N$ compared to non-leguminous plants due to their ability to fix nitrogen directly from the atmosphere (Handley and Raven 1992). Therefore, humans consuming a diet featuring legumes also have relatively depleted $\delta^{15}N$, potentially masking the higher-trophic-level input of animal products or manured cereals.

The stable isotopic values from bone collagen represent a long-term average of diet, approximately over the last decade of life. However, bone turnover rate can vary depending on factors such as age, nutritional status, and the particular bone that has been sampled for analysis (Hedges et al. 2007; Tieszen et al. 1983). Furthermore, the $\delta^{13}C$ in bone collagen is biased towards the protein portion of the diet (Ambrose and Norr 1993; Tieszen and Fagre 1993), and the $\delta^{15}N$ effectively represents only the protein component of the diet, meaning the dietary contribution from the lipid and carbohydrate portions of food will be underrepresented in bone collagen. This is particularly important when considering a protein-poor crop such as maize, which will be underrepresented in measurements on bone collagen in terms of its caloric importance.

3. Materials and Methods

The sites featuring in this study are located along the courses of the Aconcagua and La Ligua River Valleys, and include both coastal and inland settings. Some, such as Estadio de Quillota and Valle Hermoso, are large cemetery complexes with varying levels of contextual information available from excavation reports (Baeza 2010; Didier and Ávalos 2009a; 2009b; Gajardo-Tobar and Silva 1970; Kaltwasser 1968), while others are isolated finds resulting from salvage recovery with extremely limited information available. Coastal sites are defined as those located on the coastal plain, on the western side of the coastal cordillera, which runs parallel, within c.5-15km of the coastline depending on location. Inland sites are those located within the

coastal cordillera or further into the inland valley, and in the case of the Aconcagua Valley around the upper basin of the watershed.

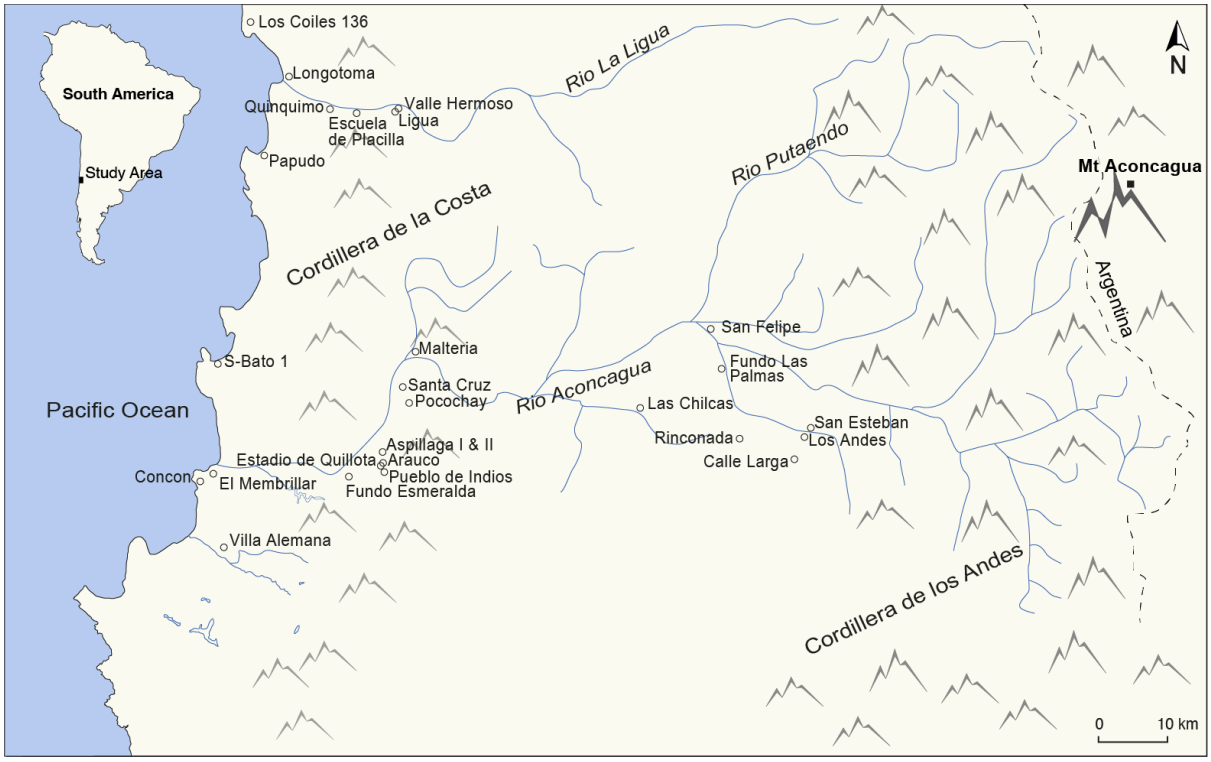


Figure 1: *Map of study area showing the location of archaeological sites included in the study.*

3.1 HUMAN AND FAUNAL BONE SAMPLES

Samples of human bone were selected for stable isotope analysis from 256 individuals from the skeletal collections held in four museums: the Museo Historico-Arqueologico de Quillota, Museo de Historia Natural de Valparaíso, Museo de Los Andes and Museo La Ligua (Table 2). Of these samples, 18 were selected for AMS radiocarbon dating from Valle Hermoso (*n* = 15), a large cemetery in La Ligua Valley, and from the Upper Basin of the Aconcagua Valley (*n* = 3). These new radiocarbon dates will complement 22 existing radiocarbon dates on bone collagen of individuals from the large cemetery at Estadio de Quillota in the Aconcagua Valley (Swift et al. 2022). Chronology has been estimated for the remaining individuals in the stable isotope analysis sample using information from excavation reports where relative dating has been applied either to whole sites, or sometimes individual burials, and based on ceramic typochronologies or burial practices.

Setting	Temporal	Site	Number of Individuals	Adult (>18 years)			Subadult (5-18 years)	Museum^
				F	M	I		
Coast	**All**	**All**	**22**	**8**	**7**	**2**	**5**	
	ECP	**All**	**11**	**5**	**5**	**1**	**0**	
		Aconcagua Valley	**3**	**0**	**2**	**1**	**0**	
		El Membrillar II	1	0	1	0	0	MHAQ
		S Bato-1	2	0	1	1	0	MHAQ
		La Ligua Valley	**8**	**5**	**3**	**0**	**0**	
		Conchales De Longotoma	1	0	1	0	0	MLL
		Concon + Camino Internacional	3	2	1	0	0	MHAQ
		Dunos De Longotoma	1	0	1	0	0	MLL
		Papudo	3	3	0	0	0	MLL
	LIP	**All**	**9**	**3**	**2**	**0**	**4**	
		Los Coiles 136	9	3	2	0	4	MLL
	LP	**All**	**2**	**0**	**0**	**1**	**1**	
		Villa Alemana	2	0	0	1	1	MHNV
Inland	**All**	**All**	**234**	**71**	**71**	**49**	**43**	
	ECP	**All**	**51**	**13**	**17**	**18**	**3**	
		Aconcagua Valley	**49**	**12**	**17**	**17**	**3**	
		Aspillaga I	5	0	0	5	0	MHAQ
		Aspillaga II	2	1	0	1	0	MHAQ
		Calle Arauco	3	3	0	0	0	MHAQ
		Calle Ricardo Santa Cruz	7	0	3	4	0	MHNV
		Calle Larga 2018	1	1	0	0	0	MLA
		Estadio De Quillota	10	2	4	3	1	MHAQ
		Fundo Esmeralda	7	2	4	0	1	MHAQ
		Fundo Las Palmas	1	1	0	0	0	MLA
		Las Chilcas	1	0	1	0	0	MHAQ
		Pocochay	2	0	2	0	0	MHNV
		Pueblo De Indios	3	1	1	1	0	MHAQ
		Los Andes Sites:*						
		Bicentenario	2	0	1	1	0	MLA
		Jumbo	1	1	0	0	0	MLA
		Santa Rosa Tumulo 2	1	0	0	1	0	MLA
		Rinconada Sites:*						
		Villa Renacer 2	1	0	0	1	0	MLA
		San Felipe Sites:*						
		Condominio Conjuillio Tocornal	1	0	0	0	1	MLA
		El Asiento Rio Putaendo	1	0	1	0	0	MLA
		La Ligua Valley	**2**	**1**	**0**	**1**	**0**	
		Valle Hermoso	2	1	0	1	0	MLL
	LIP	**All**	**54**	**14**	**17**	**8**	**15**	

		Aconcagua Valley	**16**	**6**	**4**	**4**	**2**	
		Aspillaga II	6	2	2	1	1	MHAQ
		Calle Arauco	2	1	0	1	0	MHAQ
		Calle Esmeralda S1	1	0	0	0	1	MLA
		Fundo Esmeralda	5	2	2	1	0	MHAQ
		Los Andes Sites:*						
		El Sauce	2	1	0	1	0	MLA
		La Ligua Valley	**38**	**8**	**13**	**4**	**13**	
		Escuela De Placilla	21	6	8	2	5	MLL
		Quinquimo	1	1	0	0	0	MLL
		Valle Hermoso	16	1	5	2	8	MLL
LP	**All**		**50**	**12**	**14**	**10**	**14**	
		Aconcagua Valley	**49**	**11**	**14**	**10**	**14**	
		Estadio De Quillota	47	11	13	9	14	MHAQ
		Los Andes Sites:*						
		Primera Quebrada	1	0	0	1	0	MLA
		Puente El Castillo	1	0	1	0	0	MLA
		La Ligua Valley	**1**	**1**	**0**	**0**	**0**	MLL
		La Ligua	1	1	0	0	0	
LIP/LP	**All**		**79**	**32**	**23**	**13**	**11**	
		Aconcagua Valley	**71**	**30**	**20**	**13**	**8**	
		Estadio De Quillota	56	24	15	9	8	MHAQ
		Malteria	3	1	1	1	0	MHAQ
		Los Andes Sites:*						
		La Capilla Calle Larga	1	0	0	1	0	MLA
		Los Villares 1600	1	1	0	0	0	MLA
		Rinconada Sites:*						
		Villa El Esfuerzo	1	1	0	0	0	MLA
		San Esteban Sites:*						
		Callejon Los Olivos	1	1	0	0	0	MLA
		Calle Los Reyes 1105	3	1	2	0	0	MLA
		El Hijueral	1	0	0	1	0	MHAQ
		Los Placeres La Florida	1	0	1	0	0	MLA
		Sra Mura, La Florida	1	0	0	1	0	MLA
		San Felipe Sites:*						
		Calle Padre Hurtado 1800	1	0	1	0	0	MLA
		San Vilches	1	1	0	0	0	MLA
		La Ligua Valley	**8**	**2**	**3**	**0**	**3**	
		Valle Hermoso	8	2	3	0	3	MHNV
Total			**256**	**79**	**78**	**51**	**48**	

Table 2: Samples for stable carbon and nitrogen isotope analysis

^MHAQ = Museo Histórico-Arqueológico de Quillota, MHNV = Museo Historía Natural de Valparaíso, MLA = Museo Arqueológico de Los Andes, MLL = Museo La Ligua.

**Sites within close proximity have been grouped under a subheading that corresponds to their representation on the map presented in Figure 1*

For some individuals (*n* = 79) it was only possible to determine that they belonged to one of the later, agro-pastoral periods; either the LIP or the LP. This was sometimes due to an absence of more specific contextual information, or in many instances because the timing of the transition from the LIP to the LP is equivocal (Swift et al. 2022). Many of the individuals, particularly those from Estadio de Quillota, are contemporary with this transitionary period. Therefore, a 'Later Combined' (*n* = 183) group is presented for some of the analyses and discussion of the inland isotopic data below. This group includes the isotopic data for the agro-pastoral populations, being the known inland LIP (*n* = 54) and LP (*n* = 50) individuals, as well as the 79 individuals known to be from either the LIP or the LP or the transition between them.

Sex was estimated, where possible, by morphological assessment of the pelvis and skull, employing the scoring frameworks described by Buikstra and Ubelaker (1994), which includes classifications of 'female' (F), 'probable female' (F?), 'indeterminate' (I), 'probable male' (M?) and 'male' (M). The traits assessed included mastoid process, nuchal crest, supra-orbital margin, supra-orbital ridge, mental eminence, greater sciatic notch, subpubic angle, pelvic outlet (see Buikstra and Ubelaker 1994; White and Folkens 2005 for further descriptions of traits). Comparative analysis of isotopic data was conducted both with and without the probable ('M?' and 'F?') classifications and the interpretative patterns remained consistent.

Age-at-death was estimated based on dental eruption for subadults (Ubelaker 1989), supplemented with assessment of epiphyseal fusion (Scheuer and Black 2000). For adults, age-at-death was estimated via

assessment of dental attrition as described by Lovejoy (1985). This method was chosen due to better preservation of teeth across the collections, and the inability to consistently apply other methods of estimating age-at-death due to poor preservation (e.g. Brooks and Suchey 1990; Buckberry and Chamberlain 2002). As with all osteological methods of estimating age-at-death, particularly for adults, there are some limitations with using dental attrition for this purpose: for example, the method is population-specific, it can tend to underestimate age in older age groups, the age categories can be broad, and attrition is influenced by other factors beyond just age, such as the abrasiveness of dietary components. However, similar and additional limitations are encountered for other methods of estimating age-at-death, such as cranial suture closure or assessing the quality of the pubic symphysis or auricular surface of the pelvis (Buckberry 2015; Falys et al. 2006; White and Folkens 2005). Moreover, the pubic symphysis and auricular surface often do not preserve as well as the dentition. Indeed, the primary reason for using dental attrition for estimating age in this study is that the dentition was consistently better preserved for a greater number of individuals across the collections, whereas the fragmentation and poor preservation of other skeletal elements was often an issue, particularly for the Estadio de Quillota assemblage. To maintain consistency in methodological approach, a decision was made to employ dental attrition as the primary method of ageing for adults, as using this method would ensure an age estimation for the greatest number of individuals in the sample. In cases where there were no suitably preserved teeth, a simpler estimate of 'adult' or 'subadult' was made, where possible, based on epiphyseal fusion (Buikstra and Ubelaker 1994; McKern and Stewart 1957; Scheuer and Black 2000).

For the analyses discussed in this paper, all individuals were divided into age categories of 'adult', those over the age of 18 years, or 'subadult', those between the ages of 5 and 18 years. Individuals under the age of 5 years (an additional *n*=65) are not presented here, however, their results are included within the Supplementary Material attached to this chapter. The decision was made to exclude the under 5s from further analysis in this paper in order to avoid complications in interpretation of the isotopic data due to the

effects of breastfeeding and weaning, an extensive discussion of which would go beyond the scope and length of the broader dietary analysis presented here (Fogel 1989; Stantis and Kendall 2022).

Seventeen faunal samples, found with the human material in the museum collections were also collected for analysis: 12 camelids (*Lama spp.*), 3 degus (*Octodon degus)*, and 2 marine fish (1 unidentified species and 1 *Trachurus murphyi*).

3.2 BOTANICAL SAMPLES

Modern plant samples were also collected from within the study area to provide baseline data (Table 3). These included various species of marine algae, C_3 and CAM plants, all of which were growing wild. They are all endemic species, with the exception of the lucuma (*Pouteria lucuma*), which was introduced from Peru during the pre-Hispanic era (Frézier 1717), and the prickly pear (*Opuntia ficus-indica*) which originated in Mexico before spreading into South America, and has been recorded in Late Period contexts in Central Chile (Griffith 2004; Rossen et al. 2010).

Sample	Name		Plant Part	Plant Type	Valley
18030.1	*Prosopis chilensis*	(Algarrobo)	Pod	C_3	Aconcagua
18030.2	*Prosopis chilensis*	(Algarrobo)	Seed	C_3	Aconcagua
18031	*Jubaea chilensis*	(Coquito)	Nut	C_3	Aconcagua
18032	*Jubaea chilensis*	(Coquito)	Nut	C_3	Aconcagua
18033	*Jubaea chilensis*	(Coquito)	Nut	C_3	Aconcagua
18034.1	*Drimys winteri*	(Canelo, wild pepper)	Seed/fruit	C_3	Aconcagua
18034.2	*Drimys winteri*	(Canelo, wild pepper)	Bark	C_3	Aconcagua
18035	*Cryptocarya alba*	(Peumo, Chilean acorn)	Fruit	C_3	Aconcagua
18036	*Pouteria lucuma*	(Lucuma)	Fruit	C_3	Aconcagua
18037	*Puya chilensis*	(Chagual)	Flesh/leaf	CAM	Aconcagua
18038.1	*Opuntia ficus-indica*	(Tuna, prickly pear)	Fruit	CAM	La Ligua
18038.2	*Opuntia ficus-indica*	(Tuna, prickly pear)	Leaf/flesh	CAM	La Ligua
18039	*Opuntia ficus-indica*	(Tuna, prickly pear)	Fruit	CAM	La Ligua
18040	*Opuntia ficus-indica*	(Tuna, prickly pear)	Fruit	CAM	Aconcagua
18041	*Echinopsis chilensis*	(Quisco/guillave)	Flesh	CAM	Aconcagua
18042	*Lessonia* sp.	(Tinilhue, kelp)	Leaf	Marine algae	La Ligua
18043	*Ulva* sp.	(Luche, sea lettuce)	Leaf	Marine algae	La Ligua
18044	*Durivllaea antarctica*	(Cochayuyo, bull kelp)	Leaf	Marine algae	La Ligua

Table 3: *Central Chilean botanical samples for stable carbon and nitrogen isotope analysis*

3.3 PRE-TREATMENT AND COLLAGEN EXTRACTION

Bone Samples

Collagen was extracted using a modified Longin (1971) protocol. Bone fragments were cleaned by shot blasting with aluminium oxide powder. Sub-samples were crushed and demineralised in 0.5 M HCl at 5°C for several days. The HCl solution was changed periodically until the samples ceased to evolve observable CO_2. The demineralized samples were placed into sealed tubes of pH3 H_2O and gelatinized at 70°C for 48 hours. The supernatant was filtered to remove insoluble residue using 45-90 µm Ezee-filters™ and then freeze-dried for approximately 48 hours.

Botanical Samples

All plant samples were cleaned with purified MilliU water frozen and then lypholised for 24 to 48 hours until dry. The dried material was then homogenized into bulk organic matter for each sample using a commercial blender.

3.4 STABLE ISOTOPE ANALYSIS

All samples were analysed using a Sercon 20/22 Isotope Ratio Mass Spectrometer in continuous flow mode at the Research Laboratory for Archaeology and the History of Art, University of Oxford. All material was analysed in duplicate to ensure reproducibility, with a precision greater than ± 0.2‰. Internal alanine standards of known value ($\delta^{13}C$ = -27.2 ± 0.1‰, $\delta^{15}N$ = 1.6 ± 0.2‰) were included throughout runs to enable drift correction. Matrix-matched, in-house standards of cow ($\delta^{13}C$ = -24.3 ± 0.1‰, $\delta^{15}N$ = 7.9 ± 0.2‰) and seal collagen ($\delta^{13}C$ = -12.5 ± 0.1‰, $\delta^{15}N$ = 16.1 ± 0.2‰) were also included for all analyses of bone collagen, to allow for two-point calibration of the results (Coplen et al. 2006). The $\delta^{13}C$ measurements of the plant samples were calibrated against international sucrose (IAEA-CH6 ($\delta^{13}C$ = -10.4 ± 0.0‰)) and polyethylene (IAEA-CH7 ($\delta^{13}C$ = -32.2 ± 0.1‰)). The $\delta^{15}N$ measurements of the plant samples were calibrated using alanine ($\delta^{15}N$ = 1.6 ± 0.2‰) and seal ($\delta^{15}N$ = 16.1 ± 0.2‰). The reported isotopic values are the means of the two runs in units per mil (‰) relative to international standards for $\delta^{13}C$ (VPDB) and $\delta^{15}N$ (AIR).

Collagen preservation was assessed by collagen yield (% wt greater than 1%), the weight percentages of carbon and nitrogen relative to the combusted collagen (%C between 30 and 50; %N approx. 11-16), and the atomic ratio of carbon to nitrogen (C:N between 2.9 and 3.6) (Ambrose 1990; Brock et al. 2010; DeNiro 1985; Van Klinken 1999). Fifteen human samples failed to satisfy the above criteria and have been excluded from further analysis (see Supplementary Material).

3.5 AMS RADIOCARBON DATING

The extraction and preparation of collagen for radiocarbon dating was as per the protocol outlined above for stable isotope analysis, and was not subjected to ultrafiltration. AMS radiocarbon dating was performed following the protocol outlines by Brock et al. (2010) at the Oxford Radiocarbon Accelerators Unit (ORAU) and the W.M. Keck Carbon Cycle Accelerator Mass Spectrometer (KCCMS).

All radiocarbon dates were calibrated and Bayesian models were calculated and produced using OxCal version 4.4 (Bronk Ramsey 2024). Radiocarbon dates were calibrated to a 95.4% probability range using the SHCal20 Southern Hemisphere atmospheric curve (Hogg et al. 2020). Bayesian modelling incorporates assumptions, known as priors, to constrain the calibrated probability distributions of groups of dates (Bayliss and Bronk Ramsey 2004; Bronk Ramsey 2015). It is a statistical method that can be employed to improve chronological resolution for sites and events, for example the timing of the introduction of maize as a dietary staple. Both individual dates and modelled ranges are presented at 95.4% confidence. Any modelled results are presented in italics.

3.6 STATISTICS

Statistical analyses were carried out using R version 3.5.0 (RCoreTeam 2018) with RStudio 1.3.1056 (RStudioTeam 2020). Pearson correlation tests were used to determine the relationship between $\delta^{13}C$ and $\delta^{15}N$. Both the $\delta^{13}C$ and $\delta^{15}N$ were found to be non-normally distributed when assessed with a Shapiro-Wilk test ($\delta^{13}C$ $W = 0.876$, $p < 0.000$ and $\delta^{15}N$ $W = 0.913$, $p < 0.000$). Therefore, non-parametric tests (Mann-

Whitney U and Kruskal-Wallis) were used for all subsequent comparisons of central tendency. Post-hoc Bonferroni corrections were applied with Kruskal-Wallis tests in cases of multiple comparisons.

Data was standardised when combining sub-groups of variables from across multiple sites for the purpose of statistical comparison. For example, if comparing the $\delta^{13}C$ values of females from all the LP sites in this study with the $\delta^{13}C$ values of males from all the LP sites, it is important to standardise the raw male and female $\delta^{13}C$ data for each site. Essentially, this puts the data for the chosen variables from each site on the same scale, allowing them to be combined in a way that they do not contribute unequally to the results and create a bias in the analysis (Drennan 2009). In such instances, standardised Z-scores were calculated by subtracting the mean (μ) of the variable from each observed value (x) at a site, and dividing this by the standard deviation (σ) of that variable. This is represented by the formula $Z = (x-\mu)/\sigma$.

4. Results

4.1 RADIOCARBON DATING

To assist with chronological resolution and refining context for the stable isotope analyses and timing of the transition to maize agriculture, a series of radiocarbon dates were obtained for the large cemetery site of Valle Hermoso in La Ligua, and some of the isolated upper basin sites in the Aconcagua Valley (Table 4). These new dates complement recently published results from EDQ in establishing a more reliable chronological framework for this area of Central Chile (Swift et al. 2022).

Lab Code	Sample	Individual	Burial	^{14}C yrs BP	±	Calibrated Date (95.4%)	% Coll.	%N	%C	C:N	$\delta^{13}C$	$\delta^{15}N$
UCIAMS 206822	VH17128	1		665	20	cal AD 1301-1395	16.05	16.29	45.42	3.25	-15.30	5.29
UCIAMS 206823	VH17135	13		670	15	cal AD 1301-1394	7.17	14.71	40.67	3.23	-10.54	9.46
UCIAMS 206824	VH17136	14		680	15	cal AD 1297-1392	16.49	15.79	44.15	3.26	-12.94	7.13
UCIAMS 206825	VH17141	21		740	15	cal AD 1276-1379	13.29	15.37	42.86	3.25	-11.50	9.08
UCIAMS 206826	VH17146	28		695	15	cal AD 1292-1388	12.64	14.62	41.87	3.34	-11.00	8.68
UCIAMS 206827	VH17159	44		680	15	cal AD 1297-1392	15.42	14.48	39.85	3.21	-15.00	5.49
UCIAMS 206828	VH17170	56		670	15	cal AD 1301-1394	16.26	15.60	43.43	3.25	-9.40	9.03

UCIAMS 206829	VH17154	39		755	15	cal AD 1271-1375	14.11	16.47	46.14	3.27	-11.42	10.01
UCIAMS 206830	VH17132	6		670	15	cal AD 1301-1394	8.28	14.38	40.29	3.27	-12.07	8.60
OxA V-2785-11	VH17153	37		621	23	cal AD 1316-1415	14.96	15.84	44.08	3.25	-15.11	6.31
OxA V-2785-12	VH17138	16		621	23	cal AD 1316-1415	9.80	14.70	41.48	3.29	-11.89	7.99
OxA V-2793-26	VH17169	53		678	23	cal AD 1297-1392	2.97	11.21	31.16	3.24	-12.12	6.15
OxA V-2735-20	VH17133	10c		1918	29	cal AD 62-216	9.94	15.17	43.55	3.34	-18.82	7.56
OxA V-2735-21	VH17143	24		668	27	cal AD 1299-1395	12.21	14.80	42.60	3.36	-14.82	5.11
OxA V-2735-22	VH17157	42		610	28	cal AD 1316-1426	13.83	13.81	38.89	3.28	-10.50	8.43
UCIAMS 206831	LA18010	719C		800	15	cal AD 1227-1284	5.38	15.09	41.88	3.24	-12.74	7.41
UCIAMS 206832	LA18021	732		545	15	cal AD 1408-1442	6.02	12.56	36.19	3.36	-11.27	5.63
UCIAMS 206833	LA18023	740		1740	20	cal AD 251-409	6.43	9.70	27.28	3.28	-18.01	4.25
OxA V-2735-19*	Ar16016	2		2311	30	399-196 cal BC	10.00	16.11	45.12	3.27	-21.20	5.61
OxA V-2735-13*	EDQ17034	112	63	2203	29	360-112 cal BC	5.08	11.71	33.00	3.28	-21.54	4.37
OxA V-2730-57*	EDQ16099	43	27	2095	29	146 cal BC-cal AD 22	8.61	12.60	35.00	3.24	-21.09	4.51
OxA V-2737-44*	EDQ17061	78		1837	30	cal AD 127-340	5.68	12.04	33.35	3.23	-20.36	4.45
OxA V-2730-55*	EDQ16079	22	12	722	25	cal AD 1278-1386	3.24	12.61	35.07	3.25	-12.56	6.67
OxA V-2735-12*	EDQ17012	88	45	721	29	cal AD 1276-1389	5.01	14.83	41.64	3.28	-9.55	7.64
OxA V-2735-9*	EDQ16104	48	30	702	26	cal AD 1284-1390	6.31	12.64	35.59	3.29	-9.58	8.98
OxA V-2735-16*	EDQ17056	136	76	693	28	cal AD 1288-1392	3.49	11.89	33.56	3.29	-13.02	6.87
OxA V-2735-15*	EDQ17052	127	74	690	28	cal AD 1290-1392	3.15	13.07	36.19	3.23	-10.32	7.67
OxA V-2737-43*	EDQ16101	46	29	672	25	cal AD 1298-1394	5.12	11.43	32.41	3.31	-13.71	6.55
OxA V-2735-14*	EDQ17045	118	69	672	27	cal AD 1296-1395	3.89	12.73	35.21	3.23	-11.90	7.55
OxA V-2735-10*	EDQ16107	57	32	667	29	cal AD 1298-1396	15.82	14.06	38.83	3.22	-10.23	8.11
UGAMS13205*	EDQ16081	27	18	630	20	cal AD 1316-1409	3.11	14.14	39.06	3.22	-9.38	8.55
UGAMS13207*	EDQ17011	75	43	620	20	cal AD 1319-1411	3.37	9.65	26.87	3.25	-11.18	7.35
OxA V-2730-53+54*	EDQ16077	23	13	614 & 579	25	cal AD 1325-1424	3.02	13.09	36.60	3.26	-10.51	7.88
OxA V-2735-17*	EDQ17066	3	1	570	27	cal AD 1391-1444	3.33	13.74	39.07	3.32	-11.50	7.20
UGAMS13209*	EDQ17043	114	67	570	20	cal AD 1396-1436	3.59	12.79	35.78	3.26	-11.17	6.41
OxA V-2742-15*	EDQ17005	65	40	562	27	cal AD 1400-1440	3.92	10.83	29.98	3.23	-8.37	8.29
UGAMS13206*	EDQ17001	63	36	540	20	cal AD 1406-1445	2.44	5.21	15.87	3.55	-12.26	6.43
UGAMS13210*	EDQ17047	122	72	540	20	cal AD 1406-1445	2.89	13.66	39.38	3.36	-10.42	7.11
OxA V-2730-56*	EDQ16083	28	19	515	26	cal AD 1410-1455	10.73	16.37	44.61	3.18	-11.05	7.57
OxA V-2735-18*	EDQ17070	2	2	507	27	cal AD 1413-1458	5.51	14.40	40.55	3.29	-11.19	8.44

Table 4: *New radiocarbon dates for Valle Hermoso (sample codes with prefix 'VH'), two Upper Basin sites, El Sauce (LA18010) and Puente El Castillo (LA18021), and one Inland Valley site Fundo Las Palmas (LA18023).*

**Estadio de Quillota dates from Swift et al. (2022)*

The $\delta^{13}C$ and $\delta^{15}N$ values of the directly dated individuals were compared with the relatively dated individuals for each temporal period (ECP, LIP and LP). For each of the chronological periods, the relatively dated individuals were not significantly different in their stable isotope values to that of the directly dated individuals, indicating the relative dating applied to the sample here is consistent with the direct radiometric dating (ECP $\delta^{13}C$: *U*=201.5 *p*=0.093, ECP $\delta^{15}N$: *U*=163.5, *p*=0.568; LIP $\delta^{13}C$: *U*=158, *p*=0.804, LIP $\delta^{15}N$: *U*=160, *p*=0.814 ; LP $\delta^{13}C$: *U*=236.5, *p*=0.875 and LP $\delta^{15}N$: *U*=182, *p*=0.257).

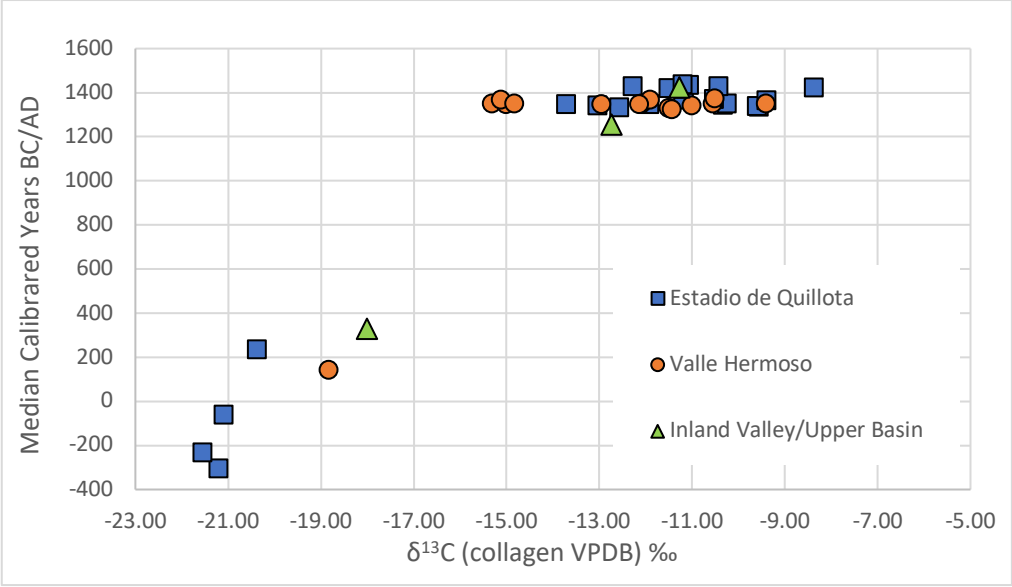


Figure 2: *Median of calibrated radiocarbon dates for Estadio de Quillota, Valle Hermoso and three Inland Valley/Upper Basin sites compared to $\delta^{13}C$ values, both measured from human bone collagen.*

The new dates follow a similar trend to that which has been observed at EDQ (Swift et al. 2022), demonstrating an earlier and a later phase of use at the sites. The median span of the earlier phase (modelled median boundaries: *460 cal BC to cal AD 422*) is about *662* years, several hundred years longer than the later phase (modelled median boundaries: *cal AD 1260-1423*) of use which is constrained to a median of *154* years. There is a significant shift to higher $\delta^{13}C$ and $\delta^{15}N$ values ($\delta^{13}C$ $p<0.000$, $\delta^{15}N$ $p<0.000$) for the directly dated individuals from the earlier and the later phases indicating the transition from a predominantly C_3 diet to a diet heavily dependent of C_4 resources occurred at some time between these two directly dates periods of use (Figure 2).

4.2 ISOTOPIC ANALYSES

Faunal and Botanical

Stable carbon and nitrogen isotope ratios were measured for 17 faunal samples (Table 5). Some previous baseline isotopic data are also available for various archaeological and modern terrestrial (*Lama* spp.), lacustrine and marine faunal resources from Central Chile (Falabella et al. 2007), and have been combined with the additional faunal material from this study (Figure 3 and Supplementary Material). The new results indicate that terrestrial mammals had diets based on C_3 plants. The only exception being one camelid (EdP17180F) from the LIP site of Escuala de Placilla in La Ligua Valley, with elevated $\delta^{13}C$ of -11.7‰, suggesting this animal was fed on maize and therefore likely domesticated.

Stable carbon and nitrogen isotope ratios were measured for modern botanical samples, including wild C_3 plants, CAM plants and marine algae, collected from the Aconcagua and La Ligua valleys. There are also $\delta^{13}C$ data, but not $\delta^{15}N$, available from broader Central Chile, encompassing parts of the study area, for various wild and cultivated modern C_3 plants, C_4 cultigens (maize) and marine algae (Falabella et al. 2007). CAM plants are typically distributed bimodally in terms of displaying either "C_3-like" or "C_4-like" stable carbon isotope values (Troughton and Card 1975). The results for the CAM plants included in this study tended towards the more C_4 end with a mean $\delta^{13}C$ value of -13.3‰, and included all of the samples (n=4) of prickly pear (*Opuntia ficus-indica*). There was one exception, a sample of *chagual* (*Puya chilensis*), a spiny bromeliad with an edible fleshy stem, which yielded a $\delta^{13}C$ value of -18.3‰.

Sample	Species	Common Name	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Terrestrial Herbivores				
VH 17179F	*Lama* sp.	Camelid	-18.1	4.6
EdP 17180F	*Lama* sp.	Camelid	-11.7	8.7
EdP 17181F	*Lama* sp.	Camelid	-21.2	6.4
EdP 17182F	*Lama* sp.	Camelid	-20.3	5.5
EDQ 17184F	*Lama* sp.	Camelid	-19.5	5.1
EDQ 17185F	*Lama* sp.	Camelid	-21.5	5.5
EDQ 17186F	*Lama* sp.	Camelid	-20.4	1.7
EDQ 17187F	*Lama* sp.	Camelid	-19.1	6.8
EDQ 17188F	*Lama* sp.	Camelid	-20.2	4.1
EDQ 17189F	*Lama* sp.	Camelid	-21.2	5.0
LA 18028F	*Lama* sp.	Camelid	-20.5	6.3
LA 18029F	*Lama* sp.	Camelid	-21.4	3.1
FE 17191F	*Octodon degus*	Degu	-22.4	5.6
FE 17192F	*Octodon degus*	Degu	-20.7	2.4
LCo 17193F	*Octodon degus*	Degu	-20.5	4.4
Marine Fish				
EDQ 17190F	Unidentified	Fish	-12.3	17.4
DL 17183F	*Trachurus murphyi*	Jurel (Inca Scad)	-12.9	14.3
C3 Plants				
18030.1	*Prosopis chilensis*	Algarrobo	-25.6	2.2
18030.2	*Prosopis chilensis*	Algarrobo	-24.5	2.5
18031	*Jubaea chilensis*	Coquito	-25.6	0.4
18032	*Jubaea chilensis*	Coquito	-24.9	-0.6
18033	*Jubaea chilensis*	Coquito	-24.1	2.1
18034.1	*Drimys winteri*	Canelo (wild pepper)	-30.7	-7.1
18034.2	*Drimys winteri*	Canelo (wild pepper)	-33.1	-7.1
18035	*Cryptocarya alba*	Peumo (Chilean acorn)	-27.5	-2.4
18036	*Pouteria lucuma*	Lucuma	-27.9	7.9
CAM Plants				
18037	*Puya chilensis*	Chagual	-18.3	
18038.1	*Opuntia ficus-indica*	Tuna (prickly pear)	-13.1	6.4
18038.2	*Opuntia ficus-indica*	Tuna (prickly pear)	-13.8	6.5
18039	*Opuntia ficus-indica*	Tuna (prickly pear)	-14.9	7.8
18040	*Opuntia ficus-indica*	Tuna (prickly pear)	-12.6	2.9
18041	*Echinopsis chilensis*	Quisco/ guillave	-12.0	-0.6
Marine Algae				
18042	*Lessonia* sp.	Tinilhue (kelp)	-18.1	11.0
18043	*Ulva* sp.	Luche (sea lettuce)	-14.3	11.8
18044	*Durivallaea antarctica*	Cochayuyo (bull kelp)	-15.5	11.3

Table 5: Stable carbon and nitrogen isotopic results from modern botanical samples, modern marine algae samples, and bone collagen of archaeological faunal samples from sites included in this study. VH = Valle Hermoso. EdP = Escuela de Placilla. FE = Fundo Esmeralda. LCo = Los Coiles 136. EDQ = Estadio de Quillota. DL = Dunos de Longotomá.

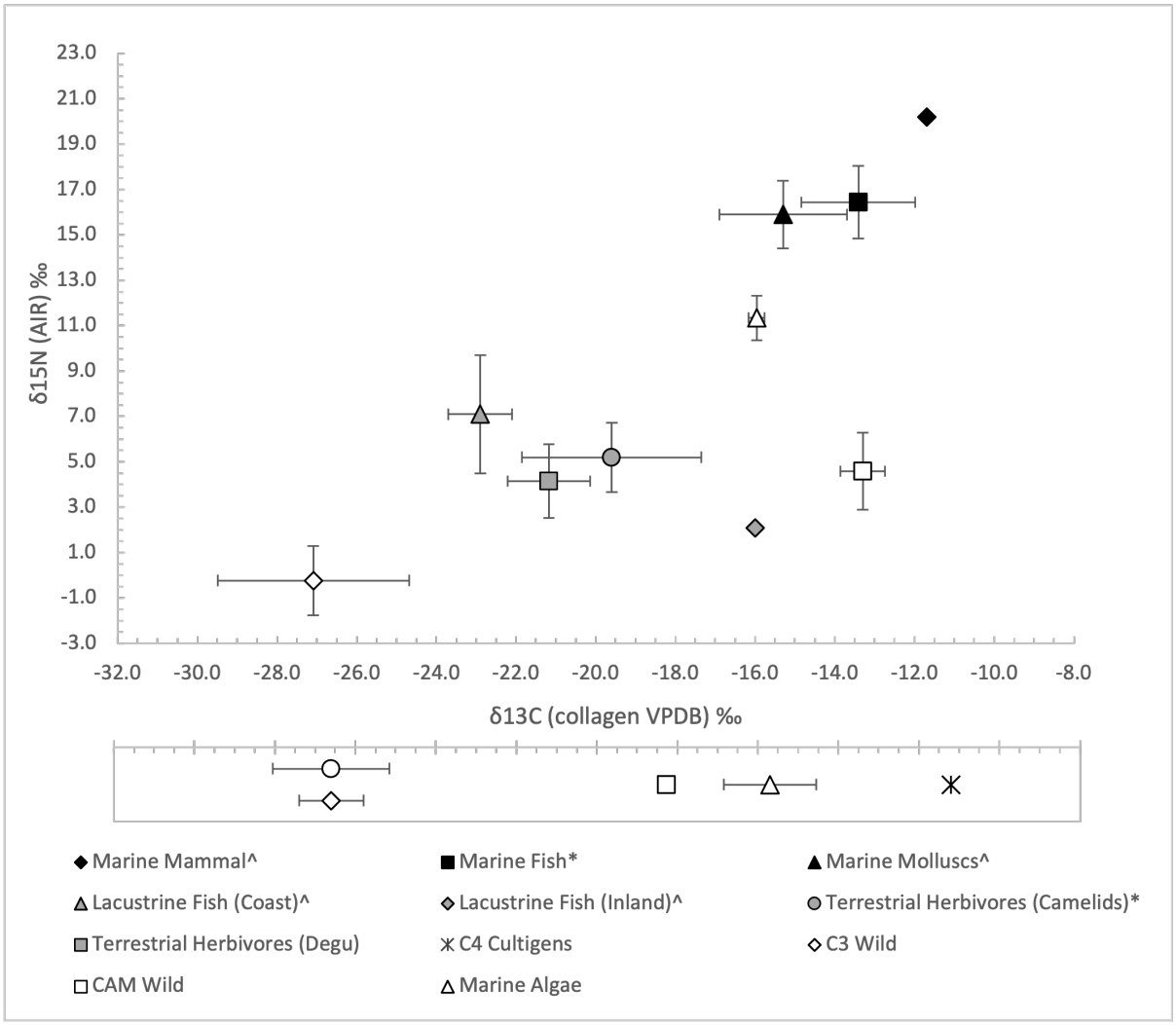


Figure 3: *Plot of $\delta^{13}C$ and $\delta^{15}N$ isotope values for Central Chilean flora and fauna. Faunal data have been combined from this study combined and previously published data, adapted from Falabella et al. (2007). Botanical data represented in the main plot with both $\delta^{13}C$ and $\delta^{15}N$ isotope values are from this study, those represented in the plot below with $\delta^{13}C$ only are from Falabella et al. (2007), with the exception of the one CAM plant in the $\delta^{13}C$ only plot.*

^Adapted from Falabella et al. (2007)

**Combined data from this study and Falabella et al. (2007).*

The isotopic data for various plant taxa in Central Chile can provide approximate $\delta^{13}C$ endpoints expected for consumers of local C_3 and C_4 plants. Based on the average -26.6‰ ± 1.8 value for both wild and cultivated C_3 plants, animals consuming an exclusively C_3 plant diet would theoretically have $\delta^{13}C$ bone collagen values

around -20.1‰ (when accounting for the +5‰ $\Delta^{13}C_{diet\text{-}collagen}$ shift, and adding an additional +1.5‰ to account for the Suess Effect). If humans had a diet featuring C_3 grazing herbivores, such as *Lama* sp., the estimated $\delta^{13}C$ endpoint for the humans would be around -19.1‰, accounting for an additional ca. 1‰ trophic level shift. An estimated $\delta^{13}C$ bone collagen endpoint for a pure C_4 diet would be around -4.7‰. However, it is very unlikely, even in heavily maize-dependent communities, that people would derive 100% of their dietary protein from C_4 plants alone. Indeed, doing so can lead to the potentially life-threatening nutritional deficiency, pellagra. Furthermore, as maize contains only about 10% protein, it is underrepresented in bone collagen compared to other more protein-rich resources (Ambrose and Norr 1993). As a guide, various studies from Central and South America have reported average $\delta^{13}C$ values of ca. -12.1 to -9.2‰ for intensive maize agriculturalists (Finucane et al. 2006; Reed 1994; Williams 2005; Williams et al. 2017).

Human Results

The results present a wide range of $\delta^{13}C$ values (-21.5‰ to -8.4‰, μ=-13.4±3.3), with highly variable but overall relatively low $\delta^{15}N$ values (4.0‰ to 16.8‰, μ=7.3±2.0) (Table 6). There is no significant difference between the $\delta^{13}C$ results from the coast compared to inland sites (*U*=2012, *p*=0.331), however the range is greater for the inland sites (range=13.1) compared to coastal (range=8.6). On the other hand, there is a significant difference in $\delta^{15}N$ with more elevated results from the coastal sites compared to inland (*p*<0.000). When the inland results are further divided into those from the 'Upper Basin' (the Los Andes area) compared to the other inland results from the eastern side of the Coastal Cordillera and Inland Valley, there is a significant decrease in $\delta^{15}N$ from west to east; from the coast, to the coastal cordillera and inland valley, to the upper basin ($\delta^{13}C$: *H(2)*=4.533, *p*=0.104; $\delta^{15}N$: *H(2)*=73.28, *p*<0.0001).

	Age Group	Sex	Setting	*n*	$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
					Mean	SD	Min	Max	Mean	SD	Min	Max
All	All	All	All	241	-13.4	3.3	-21.5	-8.4	7.3	2.0	4.0	16.8
			Coast	21	-13.8	2.8	-18.7	-10.1	11.5	2.2	8.9	16.8
			Inland	220	-13.3	3.3	-21.5	-8.4	6.9	1.4	4.0	10.9
	Adult	All	All	195	-13.5	3.4	-21.5	-8.4	7.4	2.0	4.0	16.8
			Coast	17	-14.4	2.8	-18.7	-10.1	11.6	2.4	8.9	16.8
			Inland	178	-13.4	3.4	-21.5	-8.4	7.0	1.4	4.0	10.9
		M	All	75	-12.9	3.5	-21.5	-8.4	7.9	2.3	4.0	16.8
			Coast	7	-14.0	4.8	-18.2	-11.4	12.9	2.8	9.2	16.8
			Inland	68	-12.8	3.6	-21.5	8.4	7.4	1.4	4.0	10.1
		F	All	73	-13.3	2.9	-21.4	-9.7	7.3	1.7	4.1	14.5
			Coast	8	-14.7	2.7	-18.7	-11.3	10.5	1.8	8.9	14.5
			Inland	65	-13.1	2.9	-21.4	-9.7	6.9	1.3	4.1	10.4
	Sub-adult	All	All	44	-12.6	2.4	-21.4	-9.7	7.1	1.8	4.0	13.6
			Coast	4	-11.2	0.9	-12.2	-10.4	11.5	1.6	9.7	13.6
			Inland	40	-12.7	2.5	-21.4	-9.7	6.7	1.1	4.0	8.5
ECP	All	All	All	58	-18.3	2.2	-21.5	-13.9	6.7	3.1	4.0	16.8
			Coast	11	-16.2	1.5	-18.7	-13.9	12.2	2.7	8.9	16.8
			Inland	47	-18.8	2.1	-21.5	-14.7	5.5	1.2	4.0	8.3
	Adult	All	All	55	-18.2	2.2	-21.5	-13.9	6.9	3.1	4.0	16.8
			Coastal	11	-16.2	1.5	-18.7	-13.9	12..2	2.7	8.9	16.8
			Inland	44	-18.6	2.1	-21.5	-14.7	5.5	1.2	4.0	8.3
		M	All	20	-17.9	2.8	-21.5	-15.4	7.8	4.0	4.0	16.8
			Coastal	5	-15.4	1.3	-17.3	-13.9	13.9	2.6	10.0	16.8
			Inland	15	-18.7	1.3	-17.3	-13.9	5.8	1.3	4.2	8.3
		F	All	16	-18.0	2.2	-21.4	-15.4	7.3	2.9	4.2	14.5
			Coastal	5	-16.5	1.4	-18.7	-15.4	10.7	2.3	8.9	14.5
			Inland	11	-18.7	2.3	-21.4	-15.7	5.7	1.3	4.2	8.3
	Sub-adult	All	All	3	-19.8	2.0	-21.4	-17.6	4.3	0.3	4.0	4.5
			Coastal	0								
			Inland	3	-19.8	2.0	-21.4	-17.6	4.3	0.3	4.0	4.5
LIP	All	All	All	62	-12.2	1.5	-15.7	-9.4	8.1	1.8	5.1	13.6
			Coast	9	-11.2	0.8	-12.3	-10.1	10.8	1.4	9.2	13.6
			Inland	53	-12.3	1.5	-15.7	-9.4	7.6	1.4	5.1	10.9
	Adult	All	All	43	-12.0	1.5	-15.7	-9.4	8.2	1.5	5.8	12.0
			Coastal	5	-11.1	0.9	-12.3	-10.1	10.3	1.2	9.2	12.0
			Inland	38	-12.1	1.5	-15.7	-9.4	8.0	1.3	5.8	10.9
		M	All	19	-11.5	1.5	-15.7	-9.4	8.6	1.3	6.1	12.0
			Coastal	2	-10.3	0.3	-10.5	-10.1	10.6	2.0	9.2	12.0
			Inland	17	-11.6	1.5	-15.7	-9.4	8.3	1.1	6.1	10.1
		F	All	16	-12.0	1.1	-13.9	-9.8	8.4	1.4	6.0	11.0
			Coastal	3	-11.7	0.5	-12.3	-11.3	10.1	0.8	9.6	11.0

			Inland	13	-12.1	1.2	-13.9	-9.8	8.0	1.2	5.1	10.9
	Sub-adult	All	All	19	-12.6	1.4	-15.3	-10.4	7.7	2.3	5.1	13.6
			Coastal	4	-11.2	0.9	-12.2	-10.4	11.5	1.6	9.7	13.6
			Inland	15	-12.9	1.3	-15.3	-11.0	6.6	1.1	5.1	8.5
LP	All	All	All	46	-11.0	1.2	-13.8	-8.4	7.5	1.0	5.6	11.4
			Coast	1	-11.4				11.4			
			Inland	45	-11.0	1.3	-13.8	-8.4	7.4	0.8	5.6	9.2
	Adult	All	All	34	-10.9	1.3	-13.8	-8.4	7.7	1.1	5.6	11.4
			Coastal	1	-11.4				11.4			
			Inland	33	-10.9	1.3	-13.8	-8.4	7.6	0.8	5.6	9.2
		M	All	13	-10.2	1.0	-12.3	-8.4	7.8	0.9	6.3	9.2
			Coastal	0								
			Inland	13	-10.2	1.0	-12.3	-8.4	7.8	0.9	6.3	9.2
		F	All	12	-11.4	1.1	-13.5	-9.7	7.4	0.7	6.4	8.8
			Coastal	0								
			Inland	12	-11.4	1.1	-13.5	-9.7	7.4	0.7	6.4	8.8
	Sub-adult	All	All	11	-11.3	1.1	-13.7	-9.8	7.1	0.7	6.3	8.1
			Coastal	0								
			Inland	11	-11.3	1.1	-13.7	-9.8	7.1	0.7	6.3	8.1
Later Comb.	All	All	All	183	-11.8	1.5	-16.1	-8.4	7.5	1.4	4.1	13.6
			Coast	10	-11.2	0.8	-12.3	-10.1	10.9	1.4	9.2	13.6
			Inland	173	-11.8	1.5	-16.1	-8.4	7.1	1.2	4.1	10.9
	Adult	All	All	140	-11.7	1.5	-16.1	-8.4	7.6	1.3	4.1	12.0
			Coast	6	-11.2	0.8	-12.3	-10.1	10.5	1.1	9.2	12.0
			Inland	134	-11.7	1.5	-16.1	-8.4	7.4	1.2	4.1	10.9
		M	All	55	-11.2	1.3	-15.7	-8.4	8.0	1.2	5.8	12.0
			Coast	2	-10.3	0.3	-10.5	-10.1	10.6	2.0	9.2	12.0
			Inland	53	-11.2	1.3	-15.7	-8.4	7.9	1.2	5.8	10.1
		F	All	57	-12.0	1.2	-15.3	-9.7	7.3	1.3	4.1	11.0
			Coast	3	-11.7	0.5	-12.3	-11.3	10.1	0.8	9.6	11.0
			Inland	54	-12.0	1.3	-15.3	-9.7	7.2	1.2	4.1	10.4
	Sub-adult	All	All	41	-11.2	0.9	-15.3	-9.7	11.4	1.6	5.1	13.6
			Coast	4	-11.2	0.9	-12.2	-10.4	11.4	1.6	9.7	13.6
			Inland	37	-12.1	1.4	-15.3	-9.7	6.9	0.9	5.1	8.5

Table 6: *Stable carbon ($\delta^{13}C$ [‰ $_{AIR}$]) and nitrogen ($\delta^{15}N$ [‰ $_{VPDB}$]) results for human bone collagen samples from the Aconcagua and La Ligua Valleys.*

There is a moderate, but significant positive relationship between the inland $\delta^{13}C$ and $\delta^{15}N$ values (R^2=0.447, p<0.0001). This relationship is not seen in the coastal sites (R^2=0.014, p=0.614). There is also a strong linear

correlation between the $\delta^{13}C$ results of the 32 samples with direct radiocarbon dates, with $\delta^{13}C$ increasing over time (R^2=0.866, p<0.001). The positive linear relationship between $\delta^{15}N$ and the dated samples is weaker, but still significant (R^2=0.391, p<0.001). Similarly, a significant increase is observed for both $\delta^{13}C$ and $\delta^{15}N$ across the temporal periods in an inland setting ($\delta^{13}C$: *H(2)*=100.42, p<0.0001; $\delta^{15}N$: *H(2)*=56.29, p<0.0001 (α=0.017 with Bonferroni adjustment)), while in a coastal setting a significant difference is observed across the temporal periods only for $\delta^{13}C$, but not $\delta^{15}N$ ($\delta^{13}C$: *H(2)*=15.03, p=0.001; $\delta^{15}N$: *H(2)*=1.09, p=0.581 (α=0.017 with Bonferroni adjustment)) (Figure 4).

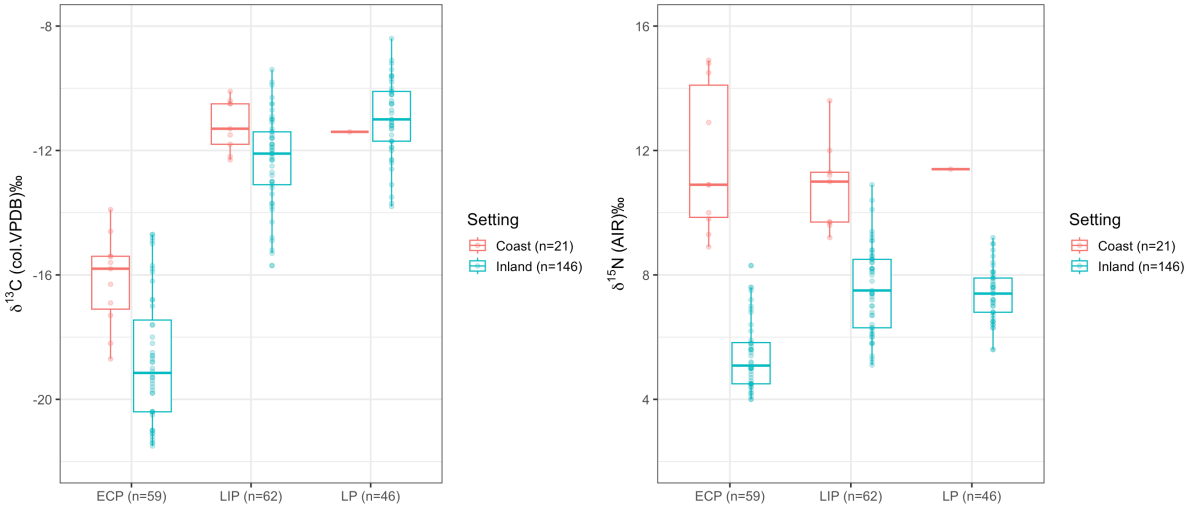


Figure 4: *Boxplots showing the variation in $\delta^{13}C$ and $\delta^{15}N$ in inland and coastal samples across the regionally defined chronological periods*

The $\delta^{13}C$ and $\delta^{15}N$ results for the recognised Central Chilean chronological periods have also been compared between the two valleys and by coastal/inland setting, between adults and sub-adults, and between adult males and females (Table 7). Significant differences between these groups were only observed among some of the inland results.

Setting	Temporal Period	Comparison	$\delta^{13}C$ *(p value)*	$\delta^{15}N$ *(p Value)*
Coast	ECP(n=11)	Aconcagua (6) vs La Ligua (5)	0.784	0.200
		Adult (11) vs Subadult (0)	.	.
		Male (5) vs Female (5)	0.402 (0.845)	0.056 (0.381)
	LIP(n=9)	Aconcagua (0) vs La Ligua (9)	.	.
		Adult (5) vs Subadult (4)	1.000 (1.000)	0.219 (0.219)
		Male (2) vs Female (3)	0.200 (0.200)	1.000 (1.000)
	LP(n=1)	.	.	.
Inland	ECP(n=48)	Aconcagua (46) vs La Ligua (2)	0.673	***0.045***
		Adult (44) vs Subadult (4)	0.317 (0.150)	***0.040*** (0.1287)
		Male (15) vs Female (11)	0.815 (0.770)	0.815 (0.696)
	LIP(n=53)	Aconcagua (15) vs La Ligua (38)	0.440	***0.018***
		Adult (38) vs Subadult (15)	0.055 ***(0.037)***	***0.002 (0.001)***
		Male (17) vs Female (14)	0.095 (0.107)	0.131 (0.315)
	LP(n=45)	Aconcagua (44) vs La Ligua (1)	.	.
		Adult (34) vs Subadult (11)	0.303 (0.188)	0.106 (0.088)
		Male (13) vs Female (12)	***0.021 (0.032)***	0.156 (0.087)
	Later Comb. (173)	Aconcagua (126) vs La Ligua (47)	***0.048***	***0.001***
		AV Coastal Cordillera (111) vs Inland Valley/Upper Basin (15)	***0.016***	***<0.000***
		AV Adults (103) vs LL Adults (31)	0.367 (0.737)	***<0.000*** (0.197)
		AV Subadults (21) vs LL Subadults (16)	***0.034*** (0.550)	***0.689*** (0.416)
		AV Male (37) vs LL Male (16)	0.253 (0.613)	***0.005*** (0.804)
		AV Female (43) vs LL Female (11)	0.250 (0.231)	***<0.000*** (0.621)
		Adult (134) vs Subadult (37)	0.109 (0.100)	***0.005 (0.001)***
		AV Adults (103) vs AV Subadults (21)	0.888 (0.441)	0.273 (0.069)
		LL Adults (31) vs LL Subadults (16)	0.037 (0.180)	***<0.000 (0.003)***
		Male (53) vs Female (54)	***0.003 (0.001)***	***0.002 (0.001)***
		AV Male (37) vs AV Female (43)	***0.009 (0.009)***	***0.007 (0.009)***
		LL Male (16) vs LL Female (11)	***0.051 (0.001)***	0.323 (0.193)

Table 7: *Comparison of dietary isotopes for the regionally defined temporal periods across the sub-groups of adults (over 18 years of age) and subadults (5-18 years of age), adult males and females, and between the two valleys. Significant results are presented in bold and italics. Data for the sub-groups of adult, subadult, male and female, were standardised per site as data from multiple sites within the valleys were combined for these sub-groups. The results of Mann-Whitney U tests for the standardized data are presented in brackets after the results of the unstandardized data. The results for the coastal LIP were not standardized as only one site (Los Coiles 136) contributed to the LIP coastal samples. The numbers in brackets after any of the variable names are the sample number for that variable. Abbreviation AV = Aconcagua Valley, LL = La Ligua Valley*

Age: In the LIP, adults had significantly elevated $\delta^{13}C$ and $\delta^{15}N$ when compared to subadults. Adult $\delta^{15}N$ was also elevated compared to >5yr subadults in the Later Combined group (LIP, LP, those for whom it could only be distinguished that they derive from either LIP or LP and those on the transition of LIP to LP). More

specifically, this pattern was significant among the adults and subadults from the La Ligua Valley, but not the Aconcagua Valley.

Sex: There is a significant difference in $\delta^{13}C$ between males and females in the LP, with males having more elevated $\delta^{13}C$ (Figures 5 + 6). For the Later Combined group, males are more elevated in both $\delta^{13}C$ and $\delta^{15}N$ compared to females. This pattern is the same when comparing males and females from the Aconcagua Valley only. However, when comparing males and females from La Ligua Valley, the difference between the sexes is only significant for $\delta^{13}C$ in the Later Combined group.

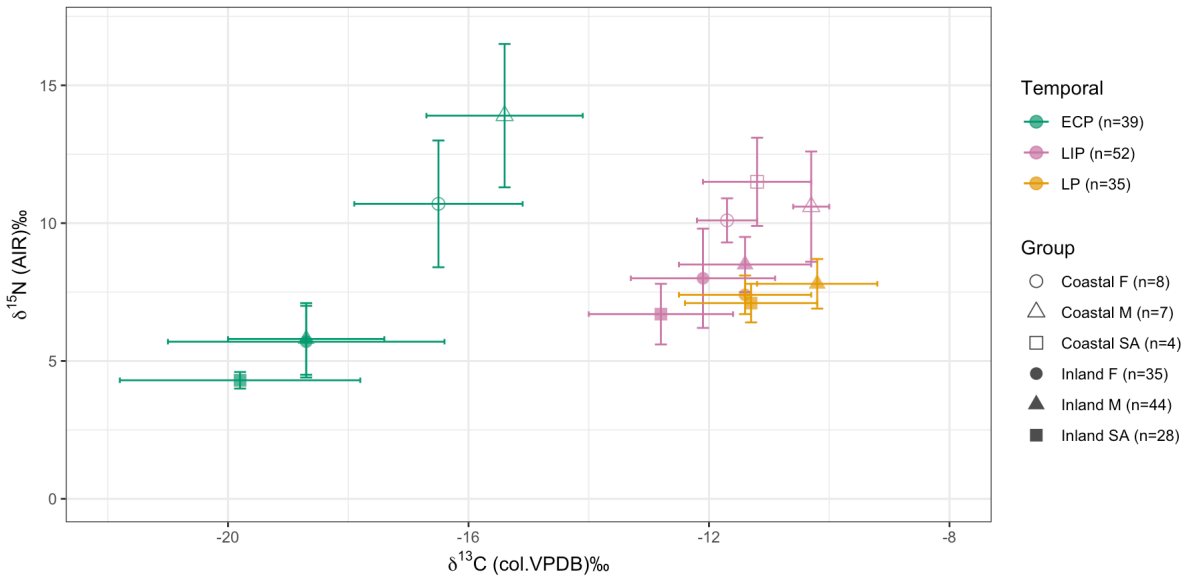


Figure 5: *Scatter plot of $\delta^{13}C$ and $\delta^{15}N$ data for the Aconcagua and La Ligua Valleys represented by chronological period (ECP, LIP, LP), geographical setting (coastal and inland), as well as age and sex (M = male, F = female, SA = subadult [5 to 18 years]).*

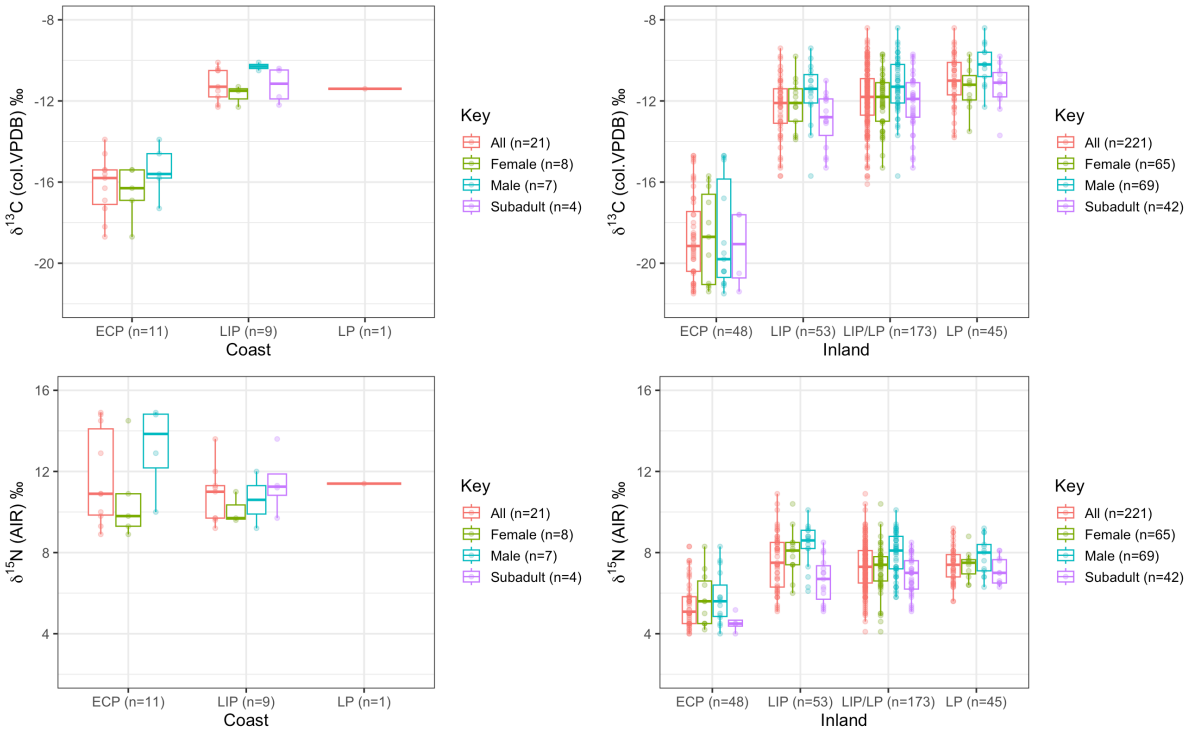


Figure 6: Boxplots for $\delta^{13}C$ and $\delta^{15}N$ data from the Aconcagua and La Ligua Valleys based on setting (coast and inland), as well as the sub-groups of male, female and subadults across the chronological periods of ECP, LIP, LP and 'Later' (a combination of results from the LIP, the LP, and individuals that could not be definitively grouped in either LIP or LP with certainty, but only to one of these Later periods more generally).

Location: Comparing the two valleys, significantly higher $\delta^{15}N$ values were noted for La Ligua Valley compared to the Aconcagua in the ECP, the LIP and the Later Combined group. A significant difference in $\delta^{13}C$ was only observed among the Later Combined group with higher values in the Aconcagua Valley. Within the Aconcagua Valley, the sites from the Upper Basin had significantly lower $\delta^{15}N$ values and lower $\delta^{13}C$ than sites from the inland Coastal Cordillera for the Later Combined Group.

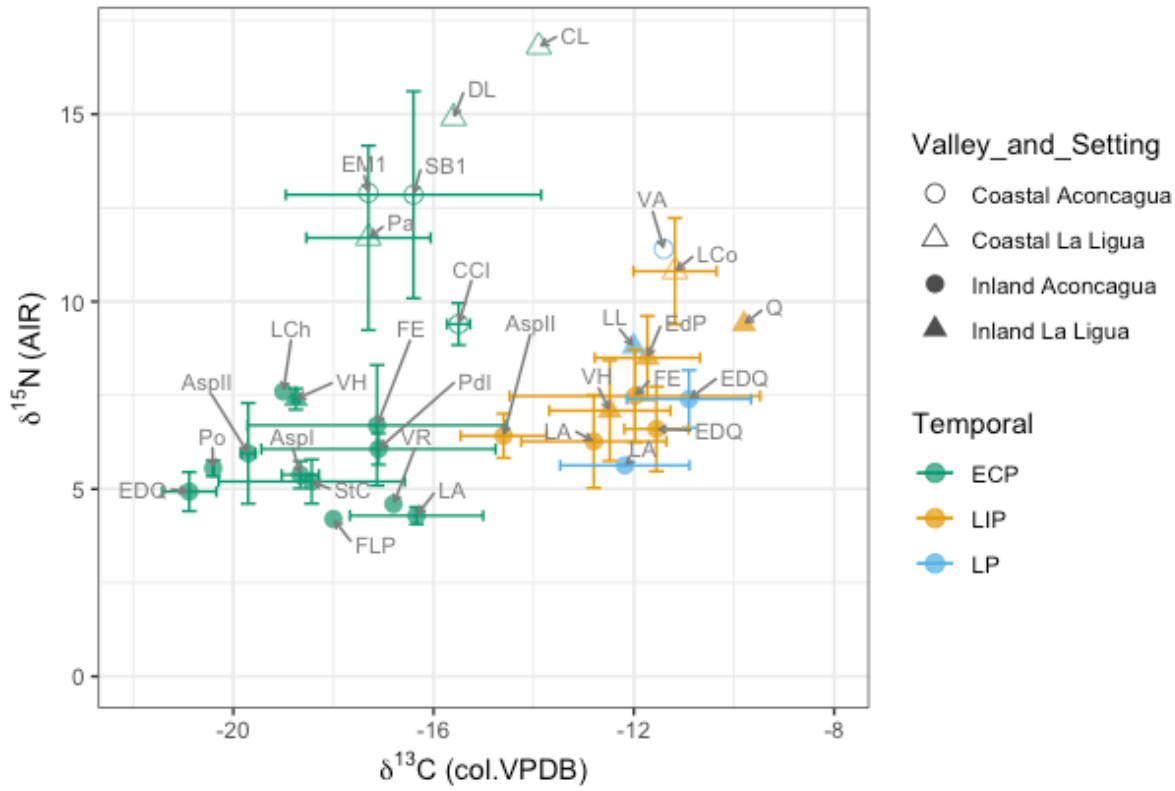


Figure 7: *Plot of mean* $\delta^{13}C$ *and* $\delta^{15}N$ values ± 1 SD *for Aconcagua (circles) and La Ligua sites (triangles).*

Coastal sites are represented by hollow symbols, and inland sites by solid symbols.

Coastal Sites:
CCl = Concon, Camino Internacional (n=3),
CL = Conchales de Longotomá (n=1),
DL = Dunos de Longotomá (n=1),
EM = El Membrillar II (n=1),
LCo = Los Coiles 136 (n=12),
Pa = Papudo (n=3),
SB1 = S-Bato 1 (n=2).
VA = Villa Alemana (n=1).

Inland Sites (Inland Valley):
Asp = Aspillaga I and II (n=14),
EDP = Escuela de Placilla (n=31),
EDQ = Estadio de Quillota and Calle Arauco (n=122),
FE = Fundo Esmeralda (n=11),
FLP = Fundo Las Palmas (n=1)
LCh = Las Chilcas (n=1),
LL = Ligua (n=1),
Ma = Maltería (n=3),
PDI = Pueblo de Indios (n=3),
Po = Pocochay (n=2),
Qi = Quinquimo (n=1),
StC = Calle Ricardo (Santa Cruz) (n=7),
VH = Valle Hermoso (n=50).

Inland Sites (Upper Basin):
LA = Los Andes (n=8),*
VR = Villa Renacer 2 (n=1).

**The data for "LA" Los Andes includes 6 different sites, each with one individual, all located within the Upper Basin town of Los Andes. These sites are Primera Quebrada, Calle Esmeralda #51, Calle Larga, El Sauce, Bicentenario, Calle Larga 2018 and San Vilches.*

5. Discussion

5.1 COASTAL DIET

The coastal sites are located along the narrow coastal plain, mostly around river mouths. Isotopically, these sites are distinguishable from the inland sites by their significantly higher $\delta^{15}N$ values (11.5‰ ± 2.2, compared to 6.9‰ ± 1.4; $p<0.000$). Elevated $\delta^{15}N$ values among the coastal sites suggests a diet supplemented with marine resources, particularly those of lower trophic levels such as molluscs or seaweeds. The $\delta^{13}C$ results (-13.8‰ ± 2.8) for these sites similarly indicate a strong marine component in the diet (Figure 7). While manured maize could also result in elevated $\delta^{13}C$ and ^{15}N values (Santana-Sagredo et al. 2021; Szpak et al. 2012), there is little archaeological evidence that would support this conclusion for coastal Central Chile, and particularly not at the ECP coastal sites. The presence of a marine component in the diet, on the other hand, is consistent with archaeological shell middens recorded at coastal sites, especially the lower-trophic-level marine resources (Ávalos 1995; Carmona et al. 2001; Seelenfreund and Westfall 2000). Likewise, among ECP coastal sites there is little evidence for cultigens and only sparse archaeobotanical evidence for maize during the latter half of the ECP at inland sites (Falabella et al. 2007; Planella et al. 2013; Roberts et al. 2013).

The coastal LIP is represented in this study only by the cemetery at Los Coiles 136, located to the north of the La Ligua river mouth . The $\delta^{13}C$ values here (-11.0‰ ± 1.1) are significantly higher than for the coastal ECP (-16.2‰ ± 1.4, $p<0.003$). The absence of a coinciding increase in $\delta^{15}N$ alongside the increase in $\delta^{13}C$ from the ECP to the LIP suggests that during the LIP coastal communities continued to utilize low-trophic-level marine foods, but also added C_4 maize to their diet, resulting in the elevated in $\delta^{13}C$ seen at Los Coiles 136. This conclusion is supported by the presence of maize at Los Coiles 136 (Ávalos 1995).

5.2 INLAND DIET

The results for the inland La Ligua and Aconcagua Valleys demonstrate variability in diets, from heavily C_3 dependent to those with a substantial contribution of C_4 foods. A range of C_3 and C_4 dietary input can be

estimated by using simple linear extrapolation between the abovementioned dietary endpoints for this region, as calculated above from the baseline floral and faunal data for Central Chile (-20.1 ± 1.8‰ for a 100% C_3 plant diet and approximately -4.7‰ for a 100% C_4 diet). Based on these proposed dietary endpoints, the range of $\delta^{13}C$ values from this study is interpreted to include diets that span from a 100% C_3 reliance at some sites in the ECP (e.g., Pocochay, mean $\delta^{13}C$=-20.4‰) through to an approximately 76% ± 10% contribution of C_4 resources at LIP Quinquimo ($\delta^{13}C$ = -8.4‰). It is important to note that this is likely to be a conservative estimate, given that maize is a low-protein food and $\delta^{13}C$ measurements on bone collagen preferentially represent the protein portion of diet, thereby underrepresenting maize contribution. However, in especially low-protein diets, non-essential amino acids will be synthesised *de novo* from the general pool of dietary carbon (Craig et al. 2009; Jim et al. 2006), to which maize would contribute strongly in the form of carbohydrates. The estimated contribution of maize could be further refined through the analysis of $\delta^{13}C$ in bioapatite (reflecting all macronutrients proportionally), and the use of Bayesian mixing models (e.g. Pestle et al. 2016), though the latter would be severely compromised by the lack of knowledge of crop isotopic values, particularly if manuring was practiced. We therefore do not employ these models here.

There is a significant elevation in $\delta^{13}C$ and $\delta^{15}N$ values across the different temporal periods from the Early Ceramic Period through to the Late Period. These findings suggest that variable quantities of animal protein were consumed, with a diachronic trend towards a greater proportion of animal protein alongside more C_4 resources being incorporated into the diet. However, it is important to note that other factors such as increasing aridity, or manuring of crops can also be a cause of elevated $\delta^{15}N$ values, as has been demonstrated in the hyper-arid Atacama Desert in Northern Chile (Santana-Sagredo et al. 2021), and may warrant further exploration in a Central Chilean context.

Overall, the $\delta^{15}N$ values for the inland sites are low (6.9‰ ± 1.3), even with an observed increase over time. The $\delta^{15}N$ values observed in the Central Chilean groups are lower than would be expected for human omnivores; those from the Early Ceramic Period (5.8‰ ± 1.2), in particular, are not significantly elevated

above the camelid herbivores in this study (*Lama guanicoe,* 5.2‰ ±1.8; *p*=0.992). It is possible that the low δ^{15}N human values relate to a negligible intake of animal protein among inland populations. There were relatively protein-rich plants available in the area, such as quinoa (*Chenopondium quinoa*) (Council 1989; Planella et al. 2013; Repo-Carrasco-Valencia and Vidaurre-Ruiz 2019), which may have provided an important alternative protein source. However, such a hypothetical near-vegan diet is contradicted by the presence of both hunting equipment, particularly at ECP sites, and abundant camelid remains (Ávalos and Saunier 2011; Falabella et al. 2016a).

Another potential explanation for the unusually low δ^{15}N in Central Chile is that nitrogen-fixing legumes featured heavily in the local diet. Nitrogen-fixing plants, which includes most legumes, are ^{15}N-depleted compared to non-leguminous plants due to their ability to fix nitrogen directly from the atmosphere (Handley and Raven 1992). As a result, humans consuming a diet featuring legumes would also have relatively low δ^{15}N. Both peanuts (*Arachis hypogaea*) and various beans (*Phaseolous* spp.) have been identified among early cultigens in Central Chile (Pardo and Pizarro 2013; Planella and Tagle 2004). Genomic analysis indicates that peanuts were most likely domesticated in Southern Bolivia, or Central Western Argentina (located across the Andes from the valleys of Central Chile) more than 8,000 years ago (Grabiele et al. 2012). The presence of beans in the archaeological record of the neighbouring Mendoza province has been directly radiocarbon dated to 401-42 cal. BC ([GrN-5398+5493] Gil 2003).

There are currently no baseline data available for the δ^{15}N values of legumes from Central Chile; however, data from Northern Chile shows the average δ^{15}N value of various locally available legumes to be 1.7‰ ±1.3 (Pestle et al. 2015; Tieszen and Chapman 1992), which is 5.2‰ lower than the mean δ^{15}N recorded in human bone collagen for Central Chile. Given there is typically a trophic level shift of about +3-5‰ for δ^{15}N (Hedges and Reynard 2007; Schoeninger and DeNiro 1984), a diet rich in nitrogen fixing legumes is a plausible explanation for the low δ^{15}N values observed in the Central Chilean population. However, this conclusion would also suggest that the early cultivation of legumes preceded that of C_4 resources (maize) in the ECP groups with entirely C_3-based diets. This possibility has not been widely discussed in terms of the use of early

cultigens in Central Chile and the timing of the introduction of various crops in the region. Nonetheless, the earlier use of legumes and cultigens other than maize has been noted in the Andes of northern Peru where macrobotanical remains of peanuts recovered from sealed house floors at preceramic sites have been directly dated to 6591-6437 cal. BC ([Beta 219588] Dillehay et al. 2007).

Another potential explanation for the low $\delta^{15}N$ values observed in human bone collagen from Central Chile may lie in the consumption of other ^{15}N-depleted foods that are local to this region. The isotopic data of botanical samples presented in this thesis represent the first measurements of $\delta^{15}N$ in edible plants in Central Chile. Two edible plants endemic to Central Chile were identified, both of which have low $\delta^{15}N$: the *coquito* (miniature Chilean coconuts [*Jubaea chilensis*]) (mean $\delta^{15}N$ 0.6‰ ± 1.4, *n*=3) and the *peumo* (Chilean acorn [*Cryptocarya alba*]) ($\delta^{15}N$ -2.4‰, *n*=1) (Table 5). The nuts from both of these plants have good potential as important dietary resources. Both have been identified in archaeological contexts (Aldunate et al. 1988; Galarce and Santander 2011; Quiroz and Belmar 2004; Rojas 1991) Indeed both *peumo* and *coquito* have been described by early European chroniclers in the area.

> *"The fruits of the peumo are the size of a jujube, they contain a butyrate substance of pleasant flavour around the core. The nationals eat it with pleasure after having cooked it in warm water"* (Molina 1810, p.158).

> *"… a red fruit, a little longer and ovate than the hazelnut, which the Indians eat cooked with other ingredients"* Ovalle (Ovalle 1646, p.57).

For *coquito*:

> *"The fruit is a coriaceous, fibrous drupe, the thickness of a walnut, containing a monospermous hazelnut and inside, a lactiginous nucleus pleasant to the taste… It grows spontaneously and in great quantity in the province of Quillota and Maule"* (Molina 1810, p.164).

"These palms usually grow in the mountains and ravines so thick, that looking at them from afar they look like hand-planted seedbeds" (Ovalle 1646, p.57).

The trees of this Chilean coconut palm grow in clusters of several hundreds and it is estimated that a single tree can produce up to 10,000 nuts which are also useful for making oil and *chicha* (Pardo and Pizarro 2013).

As such, one explanation for the unusually low $\delta^{15}N$ values observed in Central Chilean human bone collagen may therefore be that the people derived much of their dietary protein from regular consumption of nitrogen fixing legumes, or other endemic ^{15}N-depleted nuts such as the *peumo* and *coquito*, alongside the inclusion of some wild camelids. Such a diet would produce an effect of relatively low $\delta^{15}N$ values in the tissue of consumers, as is observed in Central Chile.

5.3 A RECONSTRUCTION OF DIET FROM THE EARLY CERAMIC PERIOD UNTIL THE LATE PERIOD

Early Ceramic Period (c. 300 BC – 1000/1200 AD)

The Early Ceramic is a particularly long period in Chilean archaeology, representing ca.1300+ years. A number of cultural groups, both overlapping and contemporaneous, have been described for this period. These include the Initial Ceramic Communities (ICC) (ca.300BC-ca.AD200), the Bato (ca.AD200-1000) and the Llolleo (ca.AD400-1200). The ICC were hunter-gatherers who coincide with the earliest use of pottery in Central Chile and were primarily dependent upon wild (C_3) plant resources and hunted game (Quiroz and Belmar 2004; Sanhueza and Falabella 1999). The Bato are associated with maintaining a largely hunter-gatherer subsistence dependent on C_3 resources, while also practicing some horticulture, specifically the cultivation of native quinoa which requires relatively little management and would still allow a degree of territorial mobility (Planella et al. 2010). The Llolleo, on the other hand, are generally held to have been incipient agriculturalists, more sedentary and more reliant on horticulture than their Bato counterparts.

Small, self-sufficient groups with a collective Llolleo identity established dispersed settlements throughout the middle and upper sequence of the Aconcagua Valley where they had begun to cultivate crops requiring more dedicated care such as beans, gourds, squash and maize (Planella et al. 2014; Planella and Tagle 2004). At some sites in the La Ligua Valley, such as Valle Hermoso, there is also an encroaching influence of cultural complexes from the semi-arid north of Chile, such as the El Molle.

The inland Early Ceramic Period sites have the broadest range of $\delta^{13}C$ values of all the temporal periods (from -21.5‰ to -14.7‰), suggesting considerable dietary variability (Figure 8). This distribution of $\delta^{13}C$ is bimodal with one group between -22‰ to -18‰, and another group between -17‰ and -14‰, likely representing a transition from solely C_3-based diets, to the incipient use of C_4 resources over the course of this period. The $\delta^{15}N$ distribution (from 4.0‰ to 8.3‰), on the other hand, is unimodal, although asymmetrically skewed towards the lower values.

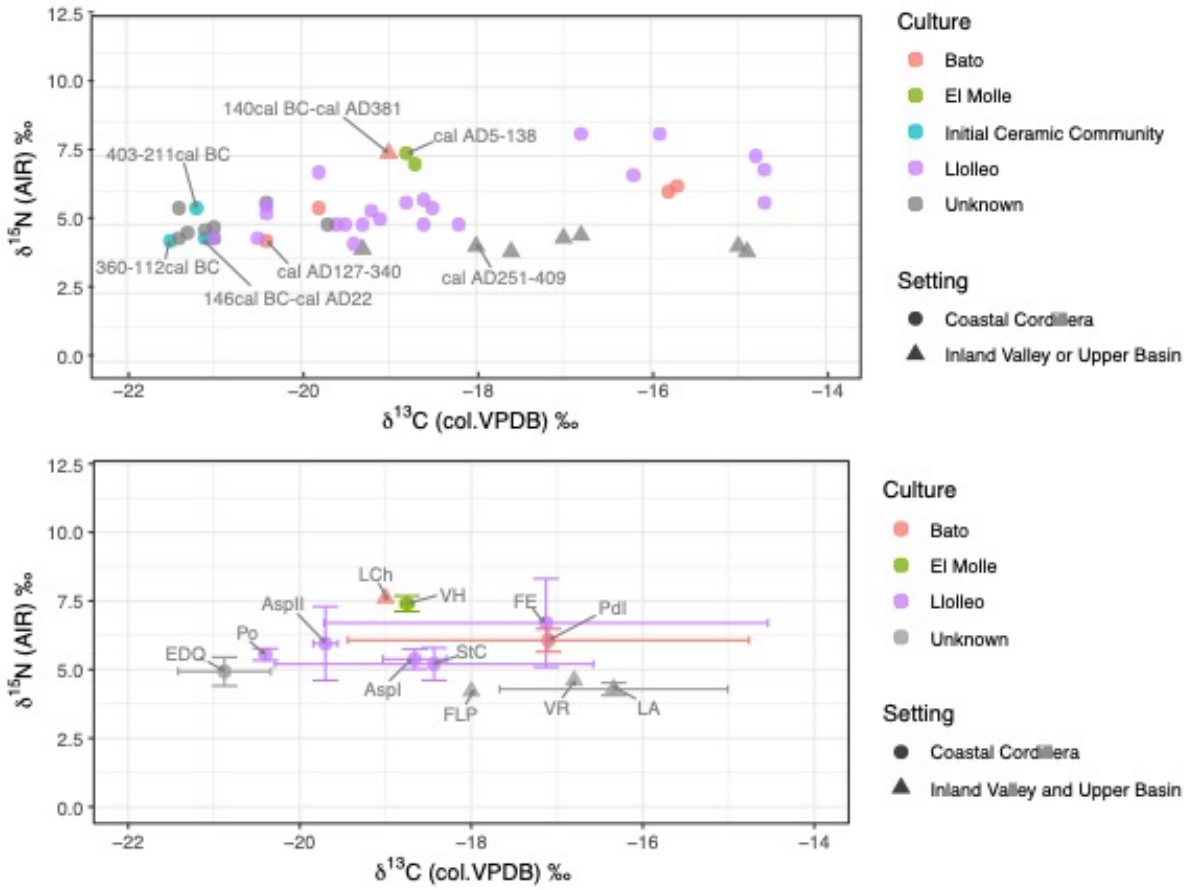


Figure 8: Scatter plots of $\delta^{13}C$ and $\delta^{15}N$ values from human bone collagen from Early Ceramic Period sites, presented by cultural group (top) and site (below).

Within the La Ligua and Aconcagua Valleys, there are no significant differences in the stable isotopic results between the sexes, or between adults and sub-adults for the ECP. Overall, the $\delta^{15}N$ values for the La Ligua Valley are significantly higher compared to the Aconcagua Valley in the ECP. However, there are only two identified ECP samples from the inland La Ligua Valley, both from the site of Valle Hermoso. The ECP burials and material culture at Valle Hermoso are different to those observed in the Aconcagua and described as representing a local cultural development, but with influences from the El Molle culture from the neighbouring semi-arid North (Rodriguez et al. 1993; Rodríguez et al. 1995). The pattern of more elevated $\delta^{15}N$ in the La Ligua Valley is not only unique to the ECP, but also persists into the later periods. It should be considered that there may be other geographical or ecological factors influencing this trend. For example, the La Ligua Valley is slightly more arid than the Aconcagua (Meteoblue 2022), which may be one contributing factor. There is also a cluster of sites in the Upper Basin of the Aconcagua Valley, which are consistently lower in $\delta^{15}N$ (U=273.5, p<0.0001).

The sites from the Inland Valley Fundo, Las Palmas and Villa Renacer (lying in the longitudinal valley between the Coastal Cordillera and the Andes Mountains), and the Upper Basin sites (three sites in the Los Andes area of the Upper Basin) tend towards higher $\delta^{13}C$ values and significantly lower $\delta^{15}N$ values.

It is generally suggested in Central Chile that dietary and subsistence patterns in the ECP are correlated with the different cultural identities recognised in this period (Falabella et al. 2016a). Previous isotopic work to the south of the current study area revealed a pattern of C_3-dependence in the Initial Ceramic Communities (ICC) from the Maipo-Mapocho and Cachapoal Basins, with comparatively low $\delta^{13}C$ and $\delta^{15}N$ (Falabella et al. 2007; Sanhueza and Falabella 2010; Tykot et al. 2009). Inland Bato individuals from the Maipo-Mapocho and Cachapoal, also had C_3-based diets (mean $\delta^{13}C$ = -18.4‰ ± 1.9), while the Llolleo had a mixed C_3-C_4 diet with much more elevated $\delta^{13}C$ (mean $\delta^{13}C$ = -14.1‰ ± 1.9). These results were interpreted to support traditional assumptions about different diets for different cultural groups (Falabella et al. 2007; Falabella et al. 2008; Sanhueza and Falabella 2010; Tykot et al. 2009).

The new data presented here from the Aconcagua and La Ligua Valleys does find some patterning in the isotopic values for the ECP when observed in relation to the different cultural affiliations for the period, but they are not as distinct as those from further south. Specifically, $\delta^{13}C$, but not $\delta^{15}N$, is significantly lower in the ICC compared to either the Bato or the Llolleo ($\delta^{13}C$ ICC vs Bato $p = 0.036$; $\delta^{13}C$ ICC vs Llolleo $p = 0.007$, adjusted using Bonferroni correction). Contexts dating to the ICC have been identified in the combined sites of Estadio de Quillota and Calle Arauco (Ávalos and Saunier 2011; Baeza 2010). The mean $\delta^{13}C$ and $\delta^{15}N$ values ($\delta^{13}C$ = -21.2‰ ± 0.2; $\delta^{15}N$ = 4.8‰ ± 0.6) for this group indicate a diet based on C_3 resources, with very low-trophic-level sources of dietary protein and/or a significant intake of nitrogen-fixing legumes, and accords with archaeological interpretation of these groups retaining a hunter-gatherer subsistence (Quiroz and Belmar 2004; Sanhueza and Falabella 1999).

The inland Aconcagua Valley samples from Bato and Lolleo contexts have very similar mean stable isotopic values ($\delta^{13}C$ $U = 50$, $p = 0.924$; $\delta^{15}N$ $U = 24$, $p = 0.126$), which is in contrast to the differing dietary patterns noted between these two cultures in the Valleys further to the south. In the Aconcagua Valley, Inland Bato $\delta^{13}C$ values range from -20.4‰ to -15.7‰ (mean =-18.1‰±2.2) and $\delta^{15}N$ from 4.4 to 7.6 (mean = 6.0‰ ± 1.2), indicating a diet based on terrestrial sources of protein with varying proportions of C_4 foods. It is important to note, however, that Bato sites are more commonly located in coastal settings, meaning that inland Bato data (n=5) is limited. The considerable variation in $\delta^{13}C$ is likewise seen at inland Llolleo sites (range=-20.5‰ to -14.7‰, mean=-18.4‰± 2.0). In the case of the Llolleo, this can be at least partly attributed to inter-site variation, with Fundo Esmeralda having the highest mean values (-17.0‰ ± 2.6), and therefore likely to have introduced some C_4 foods to the diet at this site, and Pocochay the lowest (-20.4‰ ± 0.04) with a C_3-dependent diet; the other Llolleo sites (Calle Ricardo Santa Cruz, Aspillaga I and Aspillaga II) are intermediate. The $\delta^{15}N$, on the other hand, is more consistent across sites (range 4.1‰ to 8.3‰ (mean = 5.4‰ ± 1.2)).

The $\delta^{13}C$ values for Llolleo sites in the Aconcagua Valley are much lower than those observed in the southern Maipo-Mapocho and Cachapoal Basins (Falabella et al. 2007). However, radiocarbon dates associated with the Llolleo groups to the south also indicate that they relate to the later stage of the ECP (Table 8), suggesting the difference in diet for Llolleo groups in the Aconcagua and La Ligua when compared to the Llolleo from the Maipo-Mapocho and Cachapoal may be more related to diachronic changes than to synchronic dietary differences associated with cultural affiliation to either Bato or Llolleo. Indeed, both the Bato and Llolleo from the Aconcagua are split across the bimodal $\delta^{13}C$ distribution noted above, indicating that the isotopically different diets with varying proportions of C_4 resources over the duration of the ECP were a feature for both the Bato and the Llolleo cultural complexes (Figure 9).

Site	Location/ Valley	Lab Code	^{14}C yrs BP	±	Date (cal. BC/AD) (95.4%)	Culture	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Calle Arauco	Aconcagua	OxA V2735-19[a]	2311	30	403–211calBC	ICC	-21.2	5.6
EDQ	Aconcagua	OxA V2735-13[a]	2203	29	360-112calBC	ICC	-21.5	4.4
EDQ	Aconcagua	OxA V2730-57[a]	2095	29	146calBC-calAD22	ICC	-21.1	4.5
Las Chilcas	Aconcagua	nr[b]	1930	110	144calBC-calAD387	Bato	-19.0	7.6
Valle Hermoso	La Ligua	OxA V2735-20[a]	1918	29	calAD 5-138	El Molle	-18.8	7.6
EDQ	Aconcagua	OxA V2737-44[a]	1837	30	calAD127-340	Bato	-20.4	4.5
Fundo Las Palmas, Llay Llay	Aconcagua	UCIAMS 206833	1740	20	calAD252-299 (28.7%) calAD331-413 (66.8%)	Unknown	-18.0	4.3
Valle Verde	Mapocho	Beta-213488[c]	2180	40	258-62calBC (75.2%) 356-283calBC (21.2%)	ICC	-20.3	3.8
Valle Verde	Mapocho	Beta-211328[c]	2220	40	375-133calBC (94.5%) 121-133calBC (0.9%)	ICC	-20.2	4.1
Lenka Franulic	Mapocho	AA63823[c]	1405	47	70calBC-calAD171 (90.8%) 93-83calBC (0.8%) calAD176-205 (3.95%)	ICC	-20.9	nr
Hospital 8-9	Maipo	AA68050[c]	1380	46	calAD629-775 (93.1%) calAD605-614 (0.6%)) calAD816-837 (1.8%)	Bato	-17	5.8
Paso Agricola	Cachapoal	AA64986[c]	1234	52	calAD763-981 (93.1%) calAD686-738 (9.3%)	Bato	-19.7	6.3
Lonquen	Maipo	AA68048[c]	1091	46	calAD890-1048calAD (87.1%) calAD1085-1136 (8.3%)	Llolleo	-12.7	5.7E CP
Country Club	Mapocho	AA68049[c]	1169	46	calAD840-1017 (89.5%) calAD777-813 (5.9%)	Llolleo	-13.7	5.0

Table 8: *Radiocarbon (^{14}C) dates from human bone collagen from ECP burials in Central Chile. [a]Swift et al. (2022), [b]Hermosilla (1994), [c]Falabella et al. (2007).*

nr = not reported

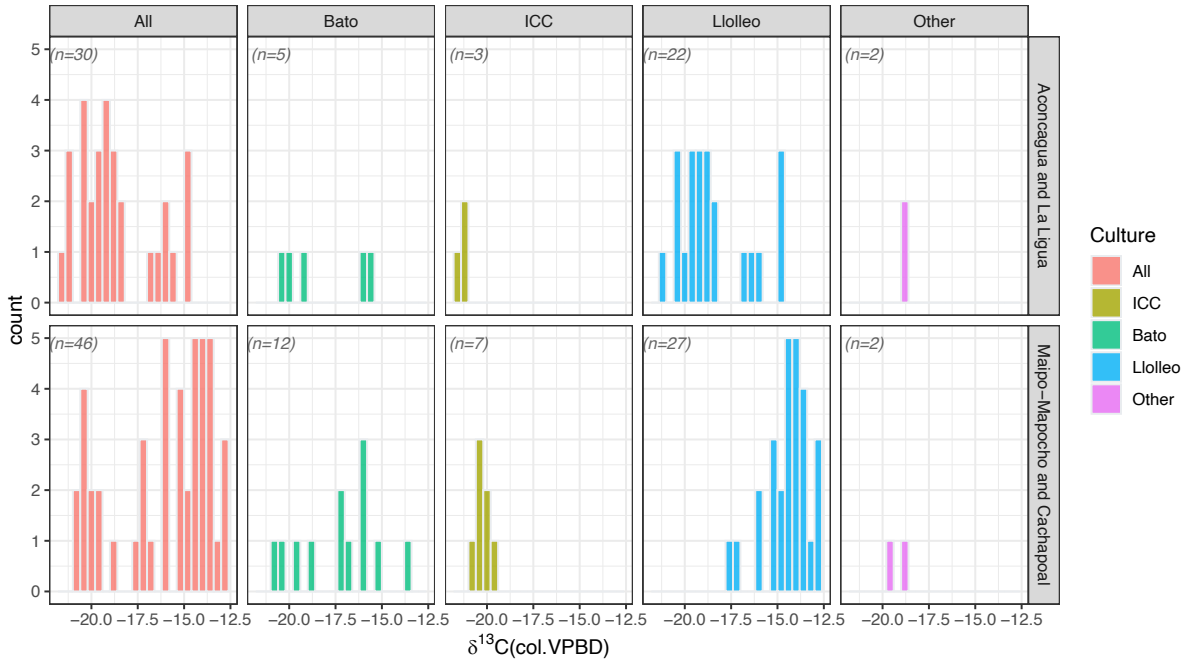


Figure 9: *Distributions of $\delta^{13}C$ for Early Ceramic Period cultural groups for the Aconcagua and La Ligua Valleys compared to the Maipo-Mapocho and Cachapoal Valleys.*

When $\delta^{13}C$ values and corresponding radiocarbon dates for ECP individuals from all of Central Chile (La Ligua Valley, Aconcagua Valley, Maipo-Mapocho Basin and Cachapoal Basin) are combined, a strong and significant linear relationship is observed between $\delta^{13}C$ values and their associated radiocarbon dates (R^2=0.75, p<0.001) (Figure 10). This relationship is not significant for $\delta^{15}N$ values and dates (R^2=0.03, p=0.320). This provides further support for the notion that dietary variation in the Central Chilean ECP may be more closely related to changes over time rather than contemporary cultural differences. This inference is, however, hampered by insufficient radiocarbon dating of archaeological sites in Central Chile, with much of the chronology for the region having been based upon ceramic typologies and thermoluminescence (TL) dates, the reliability of which has been called into question in this region (Marsh et al. 2021; Pavlovic et al. 2012; Schiappacasse et al. 1991; Swift et al. 2022).

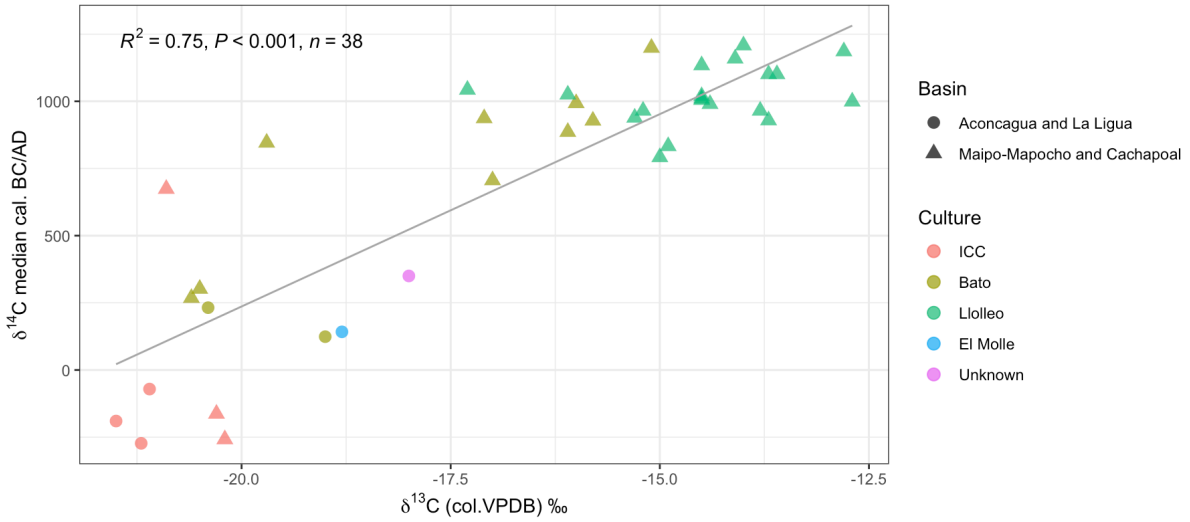


Figure 10: *Linear relationship between $\delta^{13}C$ values and their associated radiocarbon dates for individuals from Central Chile. Aconcagua and La Ligua Valleys (this study), Maipo-Mapocho and Cachapoal (Falabella et al. 2020)*

Overall, the ECP stable isotopic data from the Aconcagua and La Ligua valleys fit within a temporal trend for the broader Central Chilean region, regardless of cultural affiliation (Figures 9 + 10), suggesting that maize was incorporated into the diet alongside existing horticultural systems in the second half this period, likely commencing around ca. AD 450-600, followed by a gradual increase to the ECP/LIP transition around ca. AD 1000. This aligns with previous conclusions from the Maipo-Mapocho and Cachapoal Basins, where it has been suggested that maize was adopted into the diet between ca. AD 200 and 800 (Falabella et al. 2007; Falabella et al. 2008). These findings for Central Chile also reflect regional evidence for the arrival of maize agriculture in the Southern Andes around ca. AD 500-1000 in both the Semi-Arid North of Chile (immediately to the north of the study area) and Central Western Argentina (on the eastern side of the Andes from the study area) (Alfonso-Durruty et al. 2017; Barberena et al. 2020; Gil et al. 2006).

The Later Periods (Late Intermediate Period, Late Period, and Combined Later Periods).

Late Intermediate Period (c. 1000/1200 AD – 1350/1450 AD)

LIP individuals deriving from seven inland sites show higher $\delta^{13}C$ values (-12.3‰ ± 1.5) than the ECP, demonstrating a considerably greater dependence on C_4 resources and increasing consumption of maize compared to the preceding ECP. However, their range from -15.7‰ to -9.4‰ represents considerable variation in the proportion of maize in the diet (Figure 11). Based on the dietary endpoints estimated from the resource baseline data (see above), this equates to an estimated range of 24-67% contribution of C_4 resources (maize), with a mean around 47% contribution of maize to the diet. In spite of the range of $\delta^{13}C$ values from the LIP, the mean $\delta^{13}C$ for most of the LIP sites is relatively homogenous, with the exception of Aspillaga II, which has significantly lower $\delta^{13}C$ (H=18.53, p=0.005). Little contextual data exists for the individual burials from Aspillaga II, having been disturbed during the process of construction for public works. However, it was observed that Aspillaga I and II related to both the ECP and LIP, determined by the presence of ceramic items typical of Llolleo and Aconcagua cultures (Saunier et al. 2007). The lower LIP $\delta^{13}C$ values compared to other LIP sites, may be the result of a different diet with a lower proportion of maize, contemporaneous with the other LIP sites. Or, it might be that the LIP contexts at Aspilaga II represent an earlier stage of the LIP, around the transition from the ECP, before maize use had increased to the levels observed at other LIP sites in the Aconcagua and La Ligua Valleys. The relative homogeneity of $\delta^{13}C$ at the other LIP sites is interpreted to suggest that maize had already been adopted as a dietary staple by the LIP, unlike the ECP for which a greater, and bimodal, distribution of $\delta^{13}C$ values was observed, and displayed a clear diachronic trend.

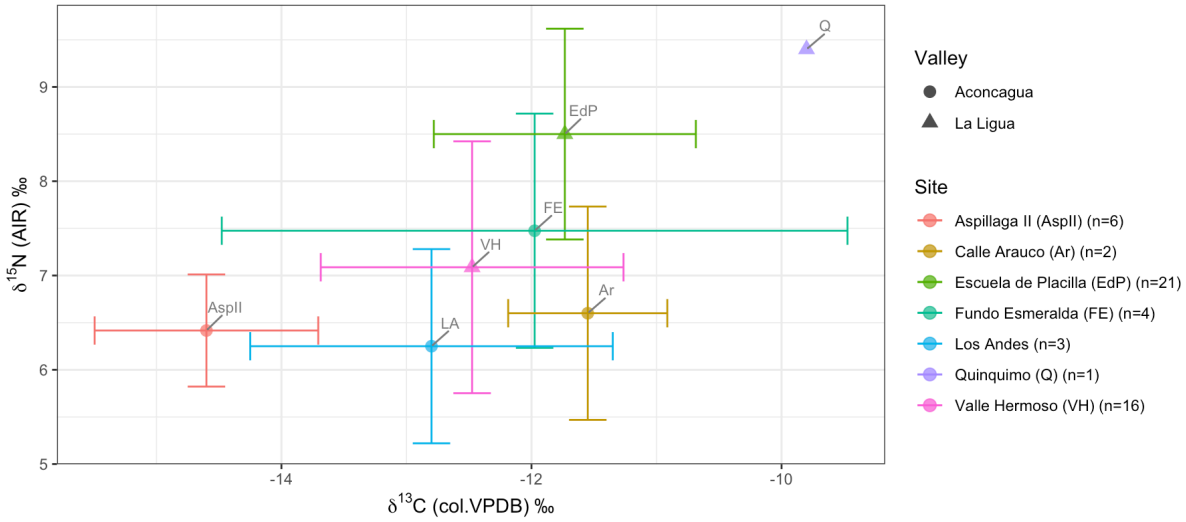


Figure 11: *Plot of $\delta^{13}C$ and $\delta^{15}N$ data for inland Late Intermediate Period sites in the Aconcagua and La Ligua valleys.*

Inferences of increased maize farming and increased consumption of animal protein during the LIP correspond with archaeobotanical and zooarchaeological evidence from Central Chile. A greater diversity of maize varieties appear in the archeological record of sites in the Santiago and Rancagua areas (the Maipo-Mapocho and Cachapoal Basins) during this period, alongside an increase in the size of maize kernels (Planella et al. 2014). An increase in the size and variety of beans, as well as the grain size of quinoa provide further evidence for an increase in agricultural practices during this period (Planella et al. 2013). Within the LIP itself, there is no significant relationship between the stable isotope results and the available radiocarbon dates ($\delta^{13}C$ R^2=0.09, p=0.288; $\delta^{15}N$ R^2=0.01, p=0.716). However, this is unsurprising given that all the currently available ^{14}C dates within the LIP are quite closely constrained to ca.150 years towards the end of the LIP (Table 9).

Sample	Lab Code	^{14}C yrs BP	±	Date (cal. AD) (95.4%)		δ^{13}C (‰)	δ^{15}N (‰)
				From	To		
LA18010	UCIAMS 206831	800	15	1227	1284	-12.7	7.4
VH17132	UCIAMS 206830	670	15	1298	1395	-12.1	8.6
VH17138	OxA V-2785-12	621	23	1318	1415	-11.9	8.0
VH17141	UCIAMS 206825	740	15	1277	1382	-11.5	9.1
VH17143	OxA V-2735-21	668	27	1276	1391	-14.8	5.1
VH17146	UCIAMS 206826	695	15	1291	1390	-11.0	8.7
VH17157	OxA V-2735-22	610	28	1296	1404	-10.5	8.4
VH17169	OxA V-2793-26	678	23	1295	1394	-12.1	6.1

Table 9: Radiocarbon (^{14}C) dates from human bone samples of Late Intermediate Period burials included in the isotopic analyses for this study.

There is a significant increase in δ^{15}N (7.6‰ ± 1.4) in the inland LIP compared to the ECP (*U*=2239, *p*<0.0001), which could suggest an increase in animal protein in the diet. An abundance of camelid (*Llama spp.*) remains supports a conclusion that guanaco meat formed an important part of LIP diets (Sanhueza and Falabella 2010). The isotopic analysis of faunal remains in this study included ten camelids, most likely guanaco (*Lama guanicoe*) (see above). Nine of the ten camelid samples yielded δ^{13}C and δ^{15}N values expected of C_3 eating terrestrial herbivores. However, the results for one camelid sample (EdP17180F) from the LIP site of Escuela de Placilla, indicated a C_4 diet for this particular animal (δ^{13}C = -11.7‰; δ^{15}N = 8.7‰). This finding supports a previous suggestion that camelids in Central Chile may have been partially domesticated or increasingly managed during the LIP, being fed on maize stover to encourage them to stay close to settlements (Becker 1994). The reliance on camelids during this period also raises the possibility of their dung being used for manuring fields, which would in turn raise crop d^{15}N values (Szpak et al. 2012) and thus complicate d^{15}N interpretation in humans.

The δ^{15}N values for this period also span a broad range from 5.1‰ to 10.9‰. This range is attributable to some variation in mean δ^{15}N values across the different inland LIP sites, with Escuela de Placilla having significantly more elevated δ^{15}N than the other sites (*U*=129, p=0.0001). This site is also responsible for the significantly higher δ^{15}N values for La Ligua compared with the Aconcagua Valley.

The La Ligua Valley is often included geographically in Central Chilean pre-history; however, it is also recognised that culturally many sites display influences from the Semi-Arid North of Chile (Norte Chico) as seen in mortuary practices and material culture (Avalos González et al. 1999; Rodríguez and Ávalos 1994; Rodríguez et al. 1995). At Escuela de Placilla a mixture of both Diaguita and local Aconcagua cultural contexts have been noted (Avalos González et al. 1999). However, it seems unlikely that the influence of Norte Chico cultures is responsible for the increased $\delta^{15}N$ at Escuela de Placilla as the same pattern is not observed at Valle Hermoso, which also has cultural influences the Semi-Arid North (Rodríguez et al. 1995), or indeed at other inland LIP sites in the semi-arid north (Becker et al. 2015).

It is unknown whether the elevated $\delta^{15}N$ at Escuela de Placilla is the result of more regular access to terrestrial animal protein, or from supplementation of marine resources in the diet, or from a different agricultural practice involving manuring of crops, or a combination of these. Furthermore, Escuela de Placilla adults have significantly higher $\delta^{15}N$ values than the subadults from the same site (U=64.5, p=0.020). In fact, the subadults from Escuela de Placilla, however, are not significantly different from the other LIP sites in the La Ligua and Aconcagua Valleys (U=59.5, p=0.374). So, it is a dietary practice particular to the adults from this site that is elevating the $\delta^{15}N$ at Escuela de Placilla.

Camelid bones have been recorded at Escuela de Placilla, but no further zooarchaeological analysis of these remains has been undertaken (Avalos González et al. 1999). Even though Escuela de Placilla is located within the coastal cordillera, and not on the coastal plain, it is closer to the Pacific coast, at approximately 13km inland, than most of the other sites, with the sole exception of Quinquimo (n=1, approximately 10km inland), where $\delta^{15}N$ is analogous at 9.4‰. It is possible that there may have been greater contact between Escuela de Placilla and coastal groups, or somewhat easier access to marine resources when compared to other coastal cordillera sites such as Valle Hermoso, which is approximately 17 km inland, and the other sites from the Aconcagua Valley. This is supported by a weak, but significant relationship between decreasing $\delta^{15}N$ values with increasing distance from the coast in the study area, but no such relationship exists for $\delta^{13}C$ ($\delta^{15}N$: R^2 = 0.13, p = 0.010; $\delta^{13}C$: R^2 = 0.04, p = 0.169; n=53).

Late Period (c.1350/1450 to 1532 cal. AD)

All except two of the inland Late Period samples are from Estadio de Quillota. The two additional inland sites with LP contexts are from the Primera Quebrada site in Los Andes area of the Aconcagua's Upper Basin, the other is from a La Ligua burial site adorned with multiple Inka ceramic offerings. The mean $\delta^{13}C$ and $\delta^{15}N$ isotopic results from the inland Late Period sites indicate an even greater reliance on C_4 resources compared to the preceding periods. A $\delta^{13}C$ range of -13.8‰ to -8.4‰ demonstrates variability in the proportion of C_4 resources consumed, representing an estimated 37-74% contribution of maize to the diets of LP individuals. The range of $\delta^{15}N$ values from 5.6‰ to 9.2‰ also indicates some diversity in the amount and source of dietary protein during this period.

When considering the isotopic data based on sex, the adult males from the inland LP have significantly higher $\delta^{13}C$ values than adult females (Table 7). This pattern also emerged between the LIP males and females, but did not reach statistical significance until the LP groups (Figure 6). The pattern is, however, also significant among the Later Combined group (discussed below). The statistical significance observed in the LP and the Later Combined may be due to increased statistical power with an increased sample size. Nonetheless, a dietary pattern is evident among the later agro-pastoral communities in Central Chile indicating that males were consuming a greater proportion of maize-based foods, as indicated by their elevated $\delta^{13}C$, compared to females. The same trend has also been observed for the LIP in the Maipo-Mapocho and Cachapoal Basins of Central Chile (Falabella et al. 2020), with the suggestion that pattern reflects differing gender roles and social hierarchies (Sánchez 1997).

Indeed, the intensification of maize agriculture has been recognised as concomitant with increasing social complexity in many parts of the Andes (Finucane et al. 2006; Hastorf and Johannessen 1993; Tung and Knudson 2018; van der Merwe et al. 1993). In Andean societies maize was consumed in various form, such as dried, popped, roasted, boiled, mashed, and fermented as *chicha* (maize beer) (Staller 2010; Staller et al. 2006; Valcárcel 1946). It is also well recognised that maize carried additional social, political and ritual

significances in many Andean societies. *Chicha* was used in political negotiations, ceremonial and festive occasions (Hastorf and Johannessen 1993; MacCormack 2004). The significance of maize beyond an economic resource was further emphasized under the Inka Empire, utilising maize as a part of the political economy related to tribute, reciprocity and labour obligations during the LP (Classen 1993; Murra 1973; Staller 2006; 2008; Staller and Thompson 2002).

The differential access to maize based on sex observed in these later periods in Central Chile is inferred to be a reflection of the increasing social complexity that often accompanied maize agriculture in the Andes. It is a pattern that suggests differing social roles and hierarchies based on gender. This finding further emphasizes a connection between the intensification of maize agriculture and broader societal changes, reinforcing a notion that gender roles may have influenced dietary practices and access to key resources in the agro-pastoral periods of Central Chile.

When comparing the LP ^{14}C dates on humans with their stable isotopic data, there is no significant linear relationship observed for either $\delta^{13}C$ or $\delta^{15}N$ ($\delta^{13}C$ R^2 = 0.043, p = 0.513; $\delta^{15}N$ R^2 = 0.026, p = 0.613) (Table 10). However, the radiocarbon dates are relatively constrained in time to the very beginning of the Late Period. Given that most LP samples for this study area are likely to relate to the transition and initial stages of the LP, it is unclear whether or not the local populations' reliance on maize changed over this period.

The Late Period is traditionally accepted to start at cal.AD 1450, although recent work from Estadio de Quillota, neighbouring Central-Western Argentina, and the Santiago metropolitan region indicates that Inka expansion into Central Chile occurred by at least cal.AD 1400, and possibly in the 14th century (Sánchez Romero 2001; Uribe and Sánchez 2016) (Marsh and Ogburn, 2017; Mundt and Marsh, 2021; Swift et al., 2022). The samples with radiocarbon dates between cal.AD 1300-1400 that have been placed into the LP for the purposes of this analysis are those which have been previously identified with LP, *Local Inka Phase* Aconcagua ceramics as burial offerings (Fuenzalida 2014) dated to cal.AD 1350 onwards (Swift et al., 2022). Other samples, either directly or relatively dated to cal. AD 1300-1400 at EDQ, but without Inka-influenced

material culture, were classified as belonging to the terminal stages of the LIP, or possibly the transitional 'LIP/LP'. As discussed above, the $\delta^{13}C$ values for these 'LIP/LP' samples were not significantly different from the other LIP samples. However, a comparison of the isotopic data for LP individuals buried with Inka-influenced ceramics dated to cal.AD 1300-1400 with those that have been classified as 'LIP/LP' and dated to cal.AD 1300-1400, demonstrates that these two groups are significantly different with LP individuals being elevated in both $\delta^{13}C$ and $\delta^{15}N$ ($\delta^{13}C$ U = 1980, p = 0.001; $\delta^{15}N$ U = 1780, p = 0.045). This finding indicates a shift in diet over a relatively short space of time that is likely aligned with the socio-political and other technological transitions associated with the arrival of Inka influence in this region.

Sample	Lab Code	^{14}C yrs BP	±	Date (cal. BC/AD) (95.4%)		$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
				From	To		
EDQ17045	OxA V-2735-14[a]	672	27	1296	1395	-11.9	7.6
EDQ 16081	UGAMS13205[b]	630	20	1316	1409	-9.4	8.6
EDQ17011	UGAMS13207[b]	620	20	1319	1411	-11.2	7.4
EDQ 16077	OxA V-2730-54[a]	579	25	1326	1440	-10.5	7.9
EDQ17043	UGAMS13209[b]	570	20	1396	1436	-11.2	6.4
EDQ17066	OxA V-2735-17[a]	570	27	1391	1444	-11.5	7.2
EDQ17005	OxA V-2742-15[a]	558	23	1400	1440	-8.4	8.4
EDQ17001	UGAMS13206[b]	540	20	1406	1445	-12.3	6.4
EDQ17047	UGAMS13210[b]	540	20	1406	1445	-10.4	7.1
EDQ16083	OxA V-2730-56[a]	515	26	1410	1455	-11.1	7.6
EDQ17070	OxA V-2735-18[a]	507	27	1413	1458	-11.2	8.4

Table 10: *Radiocarbon (^{14}C) dates from human bone samples from Late Period burials included in the isotopic analyses for this study. [a]Swift et al. (2022), [b]Fuenzalida (2014).*

There are significant differences in LP isotopic data from the study area when compared with previously published data from the semi-arid north and the Maipo-Mapocho and Cachapoal rivers of Central Chile to the south ($\delta^{13}C$ *H(2)*=40.752, *p*=0.000; $\delta^{15}N$ *H(2)*=37.855, *p*=0.000) (Table 11). The Aconcagua and La Ligua valleys are significantly more elevated in $\delta^{13}C$ than either of the neighbouring regions ($p < 0.01$) (Figure 12). All three locations are significantly different from each other in $\delta^{15}N$ values, with Aconcagua and La Ligua being intermediate to the regions to the north and south ($p < 0.01$).

Region	*n*	$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
		Mean	SD	Max	Min	Mean	SD	Max	Min
This Study, Central Chile	44	-11.0	1.3	-8.4	-13.8	7.6	0.8	9.2	5.6
Maipo-Mapocho and Cachapoal rivers, Central Chile	15	-13.2	1.2	-10.5	-15.3	5.9	1.0	8.5	4.4
Semi-Arid North (Norte Chico)	16	-12.9	0.9	-11.7	-15.2	9.2	0.9	10.9	7.0

Table 11: *Late Period stable carbon and nitrogen isotope results from bone collagen summarized for this study area, for comparison to previously published data from the Maipo-Mapocho and Cacachapoal river systems of Central Chile (Falabella et al. 2008; Sanhueza and Falabella 2010; Tykot et al. 2009) and the inland Semi-Arid North (Norte Chico) (Becker et al. 2015).*

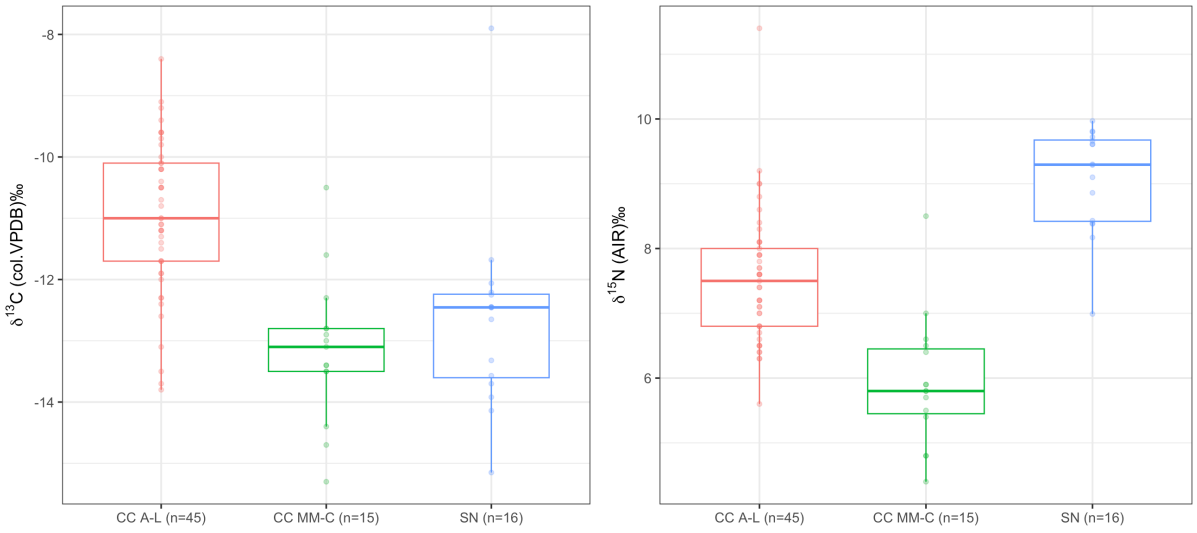


Figure 12: *Boxplots of $\delta^{13}C$ (a) and $\delta^{15}N$ (b) from inland Late Period sites from Central Chile and the semi-arid north. CC A-L = Aconcagua and La Ligua Valleys (Central Chile) (this study), CC MM-C = Maipo-Mapocho and Cachapoal Basins (Central Chile) (Falabella et al. 2008; Sanhueza and Falabella 2010; Tykot et al. 2009), SN = Semi-arid north (Norte Chico) (Becker et al. 2015).*

Based on the data currently available, it is unclear whether the differences observed between the study area and the surrounding regions are due to diachronic change or to other causes, perhaps relating to Inka imperial control of resources. The Late Period in the Semi-Arid North lacks direct dates but has been attributed to the Inka period (Becker et al. 2015). There are four thermoluminescence dates from one of six

LP sites (Línea 5 Metro) in the Maipo-Mapocho (Reyes, 2003 in Falabella et al., 2007), with the other five being relatively dated from ceramic typologies. Improved chronological resolution with a focus on absolute dating would help to illuminate why the $\delta^{13}C$ values from the Aconcagua and La Ligua Valleys are higher than those observed to the north and south of this study area. However, likely explanations could be linked to the Aconcagua's reputation as an epicentre of maize production in the region and the recent hypothesis that the Aconcagua was a hub for the diffusion of Inka influence into the region during the LP (Frézier, 1717; Mundt and Marsh, 2021; Swift et al., 2022).

Combined Later Periods (ca. AD 1000/1200 – 1532)

Many of the samples included in the present dataset could only be attributed more generally to the later periods, being either LIP or LP. This is due to several factors including ambiguity around the timing of the transition from LIP to LP in Central Chile, a dearth of absolute dates, and a lack of more specific contextual information for individual burials. In order to use the stable isotope data gathered from these samples they have been pooled into a Later Combined dataset (*n*=177) for further analysis and discussion. This includes the LIP samples (*n*=53) and the LP samples (*n*=45) discussed above, pooled with the additional 'either LIP or LP' samples (*n*=79).

When comparing the Aconcagua and La Ligua for the Later Combined period, the individuals from the Aconcagua are more elevated in $\delta^{13}C$ than those from La Ligua, however, the opposite is observed for $\delta^{15}N$ with La Ligua being more elevated than the Aconcagua. However, as discussed in the LIP section above, this difference is once again driven by the elevated $\delta^{15}N$ at Escuela de Placilla, rather than being a factor that is present for all La Ligua Valley sites.

Within the Aconcagua Valley alone, individuals from the Coastal Cordillera sites have higher $\delta^{13}C$ and $\delta^{15}N$ values than those from the Inland Valley and Upper Basin sites. This may reflect the closer proximity to the coast, and therefore potential access to and supplementation of diet with some marine resources. However, the limited archaeological evidence for consumption of marine foods, compared to terrestrial resources, at

the inland sites, alongside the overall low $\delta^{15}N$ values for the humans who occupied these sites suggests that any use of marine resources was minimal.

Among the individuals falling within the Later Combined group, it is noted that adults (over 18 years of age) have higher $\delta^{15}N$ values than subadults (5-18 year olds). This is a pattern observed within the La Ligua Valley only. Indeed, Aconcagua subadults have more elevated $\delta^{13}C$ and $\delta^{15}N$ values than La Ligua subadults. This may be pointing towards different dietary practices depending upon a person's age in the La Ligua Valley, whereas the diets were less differentiated by age in the Aconcagua Valley.

Finally, the stable isotope evidence indicates some difference in adult diet based on sex with males having higher $\delta^{13}C$ and $\delta^{15}N$ values than females. This reflects the pattern already discussed in the LP, with males having a greater access to C_4 foods; however, the Later Combined data also sees higher $\delta^{15}N$ values for males.

5.3 SEX-BASED DIFFERENCES IN DIETARY ISOTOPES

The sex-based differences in the isotopic results from the later periods, prompt further thought into how gendered identities and sociocultural roles may have impacted upon diets and access to food. A growing body of work suggests bioarchaeologists should not be interpreting data merely in terms of binary biological classifications, but instead they should be viewed through a lens of broader social and lived experiences (Geller 2021; Hollimon 2011; Stone 2018). The elevated $\delta^{13}C$ and $\delta^{15}N$ values recorded for the Later Combined periods may also be attributed to additional factors such as labour practices, ceremonial roles, or participation in redistributive feasting (Blake 2015; Staller 2006; Staller 2010).

As political centralisation and social stratification increased in the Late Intermediate and Late Periods (Falabella et al. 2016b; Moseley 2001; Uribe and Sanchez 2016), access to certain foods, such as maize and *chicha*, may have also become more gender, age, and status specific. Indeed, Turner and Klaus (2020) found

similarly elevated $\delta^{13}C$ among males compared to females in Lambayeque in Northern Peru, coinciding with increase social complexity, and argue that both dental and isotopic markers can reflect broader sociopolitical shifts, changing cultural roles and dietary restrictions and alterations relating to shifting power dynamics. Stone (2018) also argues that dietary stable isotope data, dental and skeletal pathologies may not only reflect what people ate, but also where they fitted into a society and the limits or privileges they faced.

Although the isotopic differences between sexes do not become statistically significant until the Later Combined periods, the isotopic data from the ECP through to the LP nonetheless reflect considerable intra-sex variability (see Figure 6, above). There is considerable variation in the $\delta^{13}C$ values for both males and females across each temporal period, suggesting that gendered eating experiences cannot be simply reduced to a fixed binary. Instead, it is important to also consider fluidity, intersectionality, and social context when evaluating sex-based variation and differences in isotopic data. Rather than attributing contemporaneous dietary differences to biological sex differences, it is important to also consider the impact of gendered lifeways on tasks such as food preparation, agricultural labour, or ceremonial participation, particularly among more socially complex agropastoral populations.

5.4 A REGIONAL PERSPECTIVE

A broader comparison of dietary isotopes across various settings from Chile and neighbouring Central Western Argentina demonstrates considerable dietary variability in the South Central and Central Andes (Figure 13). The Aconcagua and La Ligua Valley sit most closely with their two neighbouring Central Chilean river basins to the south, the Maipo-Mapocho and Cachapoal. Once again, the low $\delta^{15}N$ in Central Chile is striking when compared to other South Central and Southern Andean regions. As discussed above, reasonable hypotheses for such low $\delta^{15}N$ could include a dependence on nitrogen-fixing legumes, or other locally available resources with depleted $\delta^{15}N$. The broad span of $\delta^{13}C$ values over time for both Central Chile and the Semi-Arid North of Chile is also notable. The results from the Aconcagua and La Ligua Valleys, in fact, demonstrate both the lowest (inland ECP mean = -18.8‰ ± 0.6) and the highest (inland LP mean = -

11.00‰ ± 0.4) mean $\delta^{13}C$ values compared to any other inland populations represented, supporting a conclusion of considerable dietary diversity and the exploitation of a range of C_3 and C_4 terrestrial resources in varying proportions over time.

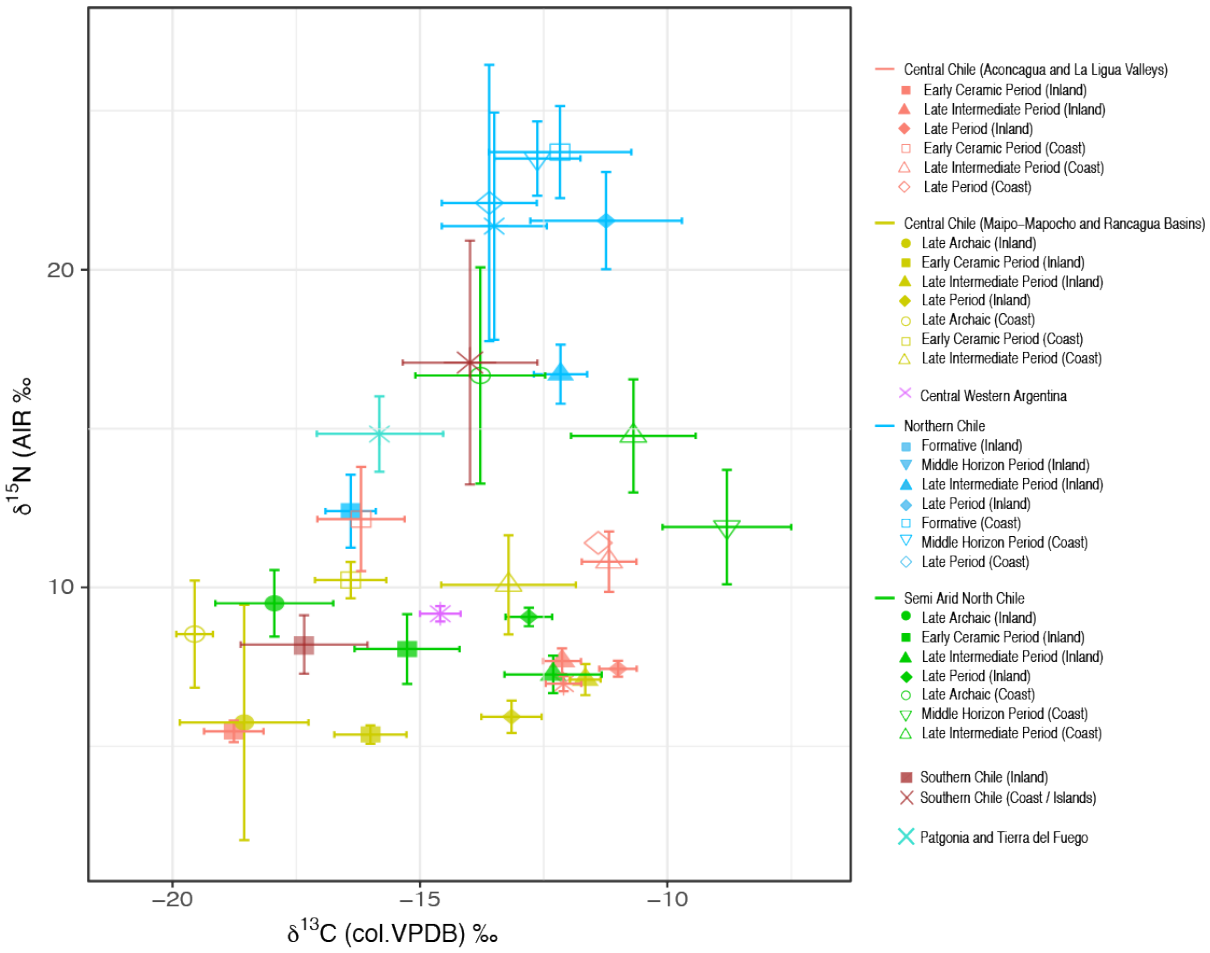


Figure 13: *Plot of $\delta^{13}C$ and $\delta^{15}N$ data for human bone collagen from pre-Columbian Chile and neighbouring regions in Argentina. Solid symbols are used for inland populations and hollow symbols represent coastal populations.*

Regions represented include: Hyper-Arid Northern Chile (Aufderheide and Santoro 1999; Petruzzelli et al. 2012; Roberts et al. 2013; Santana-Sagredo et al. 2016; Santana-Sagredo et al. 2015a; Santana-Sagredo et al. 2015b; Torres-Rouff et al. 2012); Semi-Arid Northern Chile (Alfonso-Durruty et al. 2017; Becker 1994); Central Chile – Maipo-Mapocho and Cachapoal Basins (Falabella and Sanhueza 2019; Falabella et al. 2020; Sanhueza and Falabella 2010), Central Western Argentina (Barberena et al. 2020; Fernández et al. 1999; Gil et al. 2006; Sharp et al. 2003); Southern Chile (Campbell et al. 2020); and Patagonia and Tierra del Fuego (Gómez Ortero et al. 2000; Guichón et al. 2001; Yesner et al. 2003; Yesner et al. 1991).

5.5 TIMING OF MAIZE UPTAKE IN CENTRAL CHILE

Maize was domesticated in Mesoamerica around 7000 cal. BC and reached South American by c. 6500 cal. BC (Kistler et al. 2018; Kistler et al. 2020). The earliest evidence so far of substantial maize consumption (>30% of the diet) has been recorded in Belize around 2700-2000 cal. BC (Kennet et al. 2020). In regions such as coastal Peru and the Bolivian Amazon, maize was present around 1500-500 cal. BC, although dietary intensification was delayed (Blake 2015; Burger and Van Der Merwe 1990; Dillehay 2011; Haas et al., 2013; Kistler et al. 2018). Currently, the earliest known evidence of a wild variety of maize (Zea curagua) in Central Chile has been recorded in Early Ceramic Period, Bato contexts (c. AD 200-1000) (Planella et al. 2014b; Planella 2019). The dietary stable isotope analysis presented here indicates that maize only started to be more regularly adopted in the diet around c. AD 400-600, but did not become the dominant staple until some time in the Late Intermediate Period (after c. AD 1000), much later than many other regions within the expanse of maize agriculture in the Americas during prehistory (Figure 14). This suggests a model of gradual intensification on the southern frontier of maize agriculture, rather than an immediate replacement (cf. Piperno and Pearsall 1998).

The relatively late adoption and intensification of maize as a staple cereal in this region is likely not due to ecological or geographic constraints. Rather, the delay may reflect a combination of cultural preferences, reliance on rich endemic wild resources, and subsistence strategies that did not prioritise cereal production. The fertile valleys of Central Chile were, and are, well suited to large-scale cultivation, as was observed in the post-contact periods (Falabella et al. 2016; Frezier 1717; Gil 2003). Likewise, even though Central Chile lies towards the southern periphery of the spread of maize agriculture, the Aconcagua and La Ligua Valleys held a strategic geographic location being connected to highland Andean centres and Pacific coastal exchange routes (Coros and Coros 1999; Quiroz and Belmar 2004; Uribe and Sánchez 2016). However, it is possible that cultural connections and exchange across these routes may not have intensified until the LIP and LP.

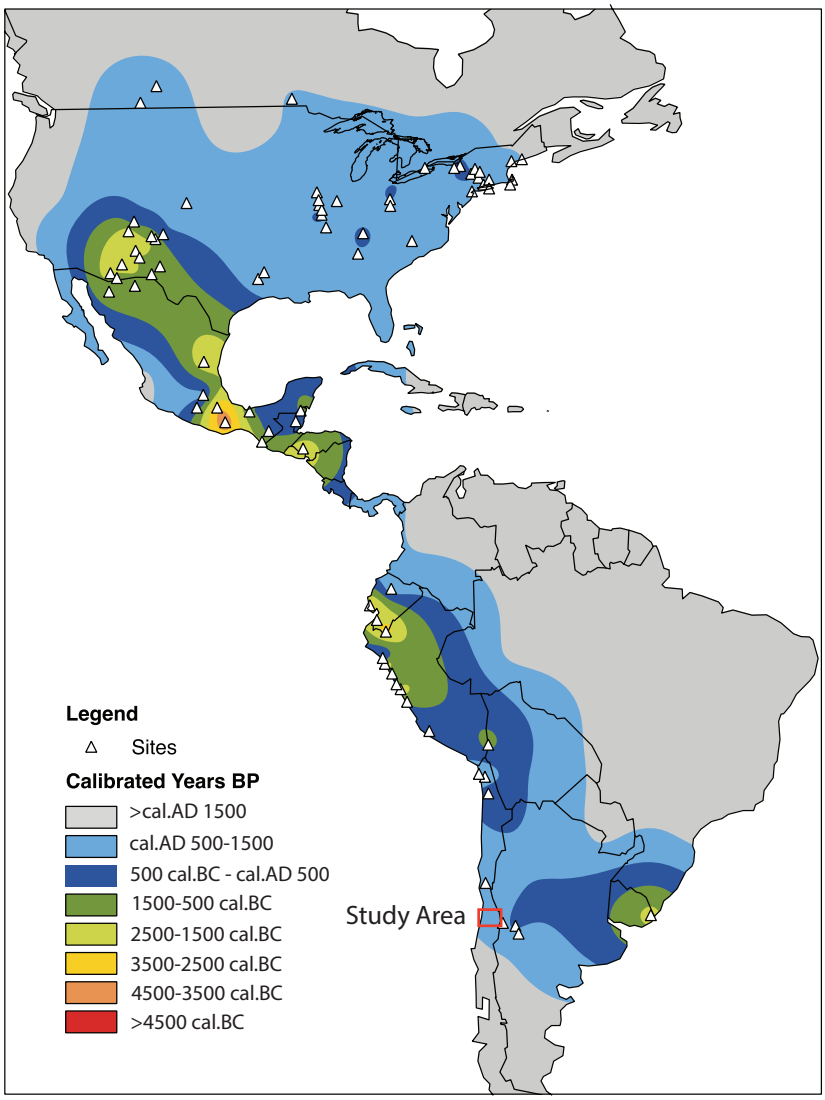


Figure 14: Chronological spread of maize agriculture across the Americas, adapted from Blake (2015), based on age distributions of archaeological sites with directly dated maize macro remains. Central Chile lies at the southern periphery of maize diffusion and exhibits a later uptake of intensive maize use compared to earlier core regions such as Mesoamerica and coastal Peru. .

In Central Chile, the region's rich terrestrial resources, including abundant endemic coquito nuts, camelids, legumes and quinoa (Falabella and Sanhueza 2019; Planella 2019; Swift et al. 2017), may have precluded an early reliance on maize. Thus, the later and gradual adoption of maize agriculture in Central Chile may have been due to an existing economic sufficiency. Indeed, the archaeological record demonstrates long-term

use of diverse local foods (Planella et al 2014; Planella and Tagle 2004; Quiroz and Belmar 2004). Similarly, the Pacific Coast of Chile provides a very rich marine economy which is essential for life in the arid north along the Atacama desert (Roberts et al. 2013; Torres-Rouff et al. 2012). However, the diets at coastal sites in Central Chile were only supplemented, rather than dominated by marine foods, it is argued due to the ample availability of terrestrial resources (Falabella and Sanhueza 2019).

A full shift to a heavy dependence on maize might simply not have been necessary, or optimal, until later socio-political changes incentivised it. Beyond its caloric value, maize's adoption may have been bound up with changes in ritual, identity, or political systems, particularly once Inka influence expanded into the region. In Mesoamerica and other parts of the Andes, maize gained ritual significance early on (Staller 2010; Staller et al. 2006). It is possible that in Central Chile, this symbolic significance did not emerge until much later, alongside other expanding social of political influences. Similar patterns of late intensification of maize have been observed in Argentina, around AD 1000–1400 and associated with emerging social complexity and interactions (Barberena et al. 2020; Gil et al. 2006). The $\delta^{13}C$ results from this research, demonstrating a later uptake of maize, somewhat echo the neighbouring region in western and northwestern Argentina. Recent $^{87}Sr/^{86}Sr$ and radiocarbon evidence from the nearby Uspallata Valley in Argentina has identified a multi-generational migration of maize farmers between cal. AD 1210-1425, just prior to Inka expansion (Barberena et al. 2023; Barberena et al. 2017). This finding in the neighbouring valleys across the Andes raises an interesting hypothesis as to whether the same migration occurred into Central Chile and was the catalyst for the intensification of maize agriculture in this region during the LIP. Nevertheless, it seems that the adoption of maize in Central Chile was not merely a consequence of diffusion from core regions, but rather a context-dependent process shaped by local environmental and ecological sufficiency, cultural preferences, and shifting sociopolitical landscapes.

6. Conclusion

This study has presented an isotopic reconstruction of dietary patterns from the ECP through until the LP in the Aconcagua and La Ligua Valleys of Central Chile, part of the southern frontier of maize agriculture in the Americas. The wide range of $\delta^{13}C$ values (-21.5‰ to -8.4‰) observed in these pre-Columbian populations demonstrates not only considerable dietary variability, but also a diachronic trend from foraging for wild C_3 resources to farming maize. The transition from a C_3-based diet to the incorporation of maize (the dominant C_4 cereal in the Southern Andes) was seen during the ECP, likely around ca. AD 450-600. The growing reliance upon maize over time is demonstrated by a marked increase in $\delta^{13}C$ values from the ECP to the LIP (ca. AD 1000), with a further peak around the LIP-LP transition (ca. AD 1300-1400). These interpretations regarding the timing of the arrival of maize agriculture in Central Chile align with broader regional patterns from the Southern Andes (Alfonso-Durruty et al. 2017; Barberena et al. 2020; Falabella et al. 2008; Gil et al. 2006) and support a conclusion of a gradual dietary transition, with increasing dependence on maize agriculture over time.

The stable isotope results from Central Chile are characterised by low $\delta^{15}N$ values (coast mean = 11.5‰ ± 2.2, inland mean = 6.9‰ ± 1.4), even among the coastal communities who included some low-trophic-level marine resources in their diet. The low $\delta^{15}N$ in human bone collagen from Central Chile could suggest a diet very low in animal protein which was supplemented with higher-protein plants such as quinoa. However, such a conclusion is inconsistent with the presence of hunting equipment and abundant camelid remains in archaeological contexts (Ávalos and Saunier 2011; Falabella et al. 2016a). An alternative hypothesis is that the $\delta^{15}N$ in human tissue has been lowered through the consumption of $\delta^{15}N$ depleted foods. For example, nitrogen-fixing legumes or another resource with depleted $\delta^{15}N$. The analysis of botanical remains in this study revealed two species of endemic edible plants with very low $\delta^{15}N$ values: *coquito* (miniature Chilean coconuts [*Jubaea chilensis*]) (mean $\delta^{15}N$ 0.6‰ ± 1.4, *n*=3) and *peumo* (Chilean acorn [*Cryptocarya alba*]) ($\delta^{15}N$ -2.4‰, *n*=1). Both of these plants have potential as important dietary resources in the region (Vivar

1988 [1558]). Their edible nuts have been identified in archaeological contexts in Central Chile and both species are endemic to this region (Aldunate et al. 1988; Galarce and Santander 2011; Quiroz and Belmar 2004).

Sex-based dietary differences were also noted among the later agro-pastoral communities, with males having greater access to maize and higher-trophic-level protein sources, indicating that maize held greater social or religious significance in the region, beyond its role as a dietary staple. This inference aligns with broader Andean patterns, where maize is recognised to have a key role in social, political and religious contexts.

Finally, further radiocarbon dating of archaeological material from these Valleys would be extremely beneficial to future research. Improved chronological resolution will allow for a more comprehensive understanding and characterisation of some of the interesting trends observed in the diets of the pre-Columbian inhabitants of the Aconcagua and La Ligua Valleys. As future research continues to refine our understandings of both spatial and temporal variability in diets and subsistence strategies on the southern frontier of maize agriculture, the findings presented here will serve as an important foundation for our understanding of dietary patterns and their intersection with broader cultural developments in the region.

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Supplementary Material:

Sample	Setting[1]	Valley[2]	Temporal[3]	Sex[4]	Age[5]	Bone Sample[6]	Collagen Yield (% wt)	%N	%C	C:N	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Ar 16016	I	A	LIP	F	A	F	10	16.1	45.1	3.3	-21.2	5.6
Ar 16017	I	A	LIP	F	A	Rib	5.5	13.6	38.2	3.3	-21	4.5
Ar 16018	I	A	LIP	uk	A	H	1.4	7.5	21.5	3.3	-12	5.8
Ar 16019	I	A	LIP	F?	A	U	1.4	13.4	37.5	3.3	-11.1	7.4
Ar 16020	I	A	LIP	F?	A	T	4.9	15.3	43.3	3.3	-21.4	5.6
AspI 16025	I	A	ECP	uk	A	H	3.2	10.8	30.2	3.3	-18.8	5.8
AspI 16026	I	A	ECP	uk	A	F	10.1	17.2	47.4	3.2	-18.6	5
AspI 16027	I	A	ECP	uk	A	F	3.1	15.9	46	3.4	-18.5	5.6
AspI 16028	I	A	ECP	uk	A	H	4.1	15.9	44.8	3.3	-19.2	5.5
AspI 16029	I	A	ECP	uk	A	F	3.4	13.3	37.5	3.3	-18.2	5
AspI 16030	I	A	ECP	uk	SA	C	1.7	10.6	30	3.3	-17.6	5.1
AspII 16031	I	A	LIP	F?	A	F	5.2	14.4	40.3	3.3	-13.9	7.4
AspII 16032	I	A	LIP	M?	A	H	5.9	11.4	31.4	3.2	-13.7	6.8
AspII 16033	I	A	ECP	uk	A	T	5.3	12.3	34.1	3.2	-19.8	6.9
AspII 16034	I	A	ECP?	M	A	Rib	4.7	13.6	37.5	3.2	-15.7	6.1
AspII 16035	I	A	ECP?	uk	A	H	2.6	11.7	33.3	3.3	-15.2	5.8
AspII 16036	I	A	LIP	F?	A	C	5.7	10.5	28.9	3.2	-13.8	6.4
AspII 16037	I	A	ECP?	uk	SA	T	3.3	13.9	38.4	3.2	-15.3	6
AspII 16038	I	A	ECP	F	A	T	4.4	14.7	40.7	3.2	-19.6	5
CCI 16043	C	A	ECP	M	A	Fi	8.7	15.6	43.5	3.3	-15.8	10
CCI 16044	C	A	ECP	F?	A	C	7	15.3	42.7	3.3	-15.4	8.9
CCI 16045	C	A	ECP	F?	A	Rib	4.7	14	38.9	3.2	-15.4	9.3
CL 17095	C	L	ECP	M	A	Rib	3.2	12.6	35.9	3.3	-13.9	16.8
DL 17094	C	L	ECP	M	A	F	2	14.3	40.3	3.3	-15.6	14.9
EdP 17096	I	L	LIP	F	A	Rib	9.4	14.5	42.8	3.4	-13.7	8.5
EdP 17097	I	L	LIP	uk	SA	H	10	16	45.1	3.3	-12.8	8.5
EdP 17098	I	L	LIP	M	A	H	4.8	14.9	42.8	3.3	-11.8	8.2

EdP 17099	I	L	LIP	M	A	H	11.7	15.6	43.6	3.3	-10.7	8.8
EdP 17100	I	L	LIP	uk	SA	C	16.6	16.6	45.7	3.2	-11.8	8.1
EdP 17101	I	L	LIP	uk	SA	C	5.1	16.3	45.5	3.3	-11.2	9.6
EdP 17102	I	L	LIP	uk	SA	Rib	9.5	14.3	39.6	3.2	-11	7.5
EdP 17103	I	L	LIP	uk	SA	F	15.9	15.6	43.4	3.2	-10	9.8
EdP 17104	I	L	LIP	uk	SA	Rib	15.5	15.7	43.7	3.2	-10.7	11.6
EdP 17105	I	L	LIP	M	A	T	4.9	15.8	43.8	3.2	-9.4	10.1
EdP 17106	I	L	LIP	uk	SA	C	16.8	16	44	3.2	-11.9	6.3
EdP 17107	I	L	LIP	uk	SA	C	10.5	15.7	43.9	3.3	-11.2	10.1
EdP 17108	I	L	LIP	uk	SA	H	8.5	14.6	40.8	3.3	-13.1	6.7
EdP 17109	I	L	LIP	M	A	H	9.7	15.9	45.2	3.3	-11.4	8.8
EdP 17110	I	L	LIP	uk	SA	T	9.1	16.4	46.1	3.3	-11.7	9.1
EdP 17111	I	L	LIP	M	A	U	6.5	15.4	43.1	3.3	-9.9	9.3
EdP 17112	I	L	LIP	M?	A	F	2.6	14.3	40.6	3.3	-11.3	9.2
EdP 17113	I	L	LIP	F	A	C	6.1	14.9	41.6	3.3	-13	8.1
EdP 17114	I	L	LIP	M	A	F	9.1	14.8	41.6	3.3	-11.6	9.1
EdP 17115	I	L	LIP	M	A	C	3.5	13.8	38.2	3.2	-12.2	8.2
EdP 17116	I	L	LIP	uk	A	H	7.5	15	42.6	3.3	-10.5	10.9
EdP 17117	I	L	LIP	F	A	Rib	3.8	14.7	41.2	3.3	-12.3	10.4
EdP 17118	I	L	LIP	uk	A	Rib	9.1	15	42.5	3.3	-12.3	8.2
EdP 17119	I	L	LIP	F	A	F	10.3	15.9	44.6	3.3	-11.6	8.4
EdP 17120	I	L	LIP	F?	A	T	9.7	15.8	44	3.2	-12.3	7.8
EdP 17121	I	L	LIP	uk	SA	C	14.4	17.6	48.9	3.2	-11.5	10.4
EdP 17122	I	L	LIP	uk	SA	C	5	15.1	42.2	3.2	-13	6.4
EdP 17123	I	L	LIP	F	A	C	9.9	16.6	45.4	3.2	-11.8	7.4
EdP 17124	I	L	LIP	uk	SA	T	17.2	18.7	51.3	3.2	-11	10.6
EdP 17125	I	L	LIP	uk	SA	Rib	15.6	16.2	44.6	3.2	-11.9	6.8
EdP 17126	I	L	LIP	uk	SA	C	8.2	14.6	40.5	3.2	-12.6	8.8
EdP 17127	I	L	LIP	uk	SA	Rib	17.9	16.6	45.4	3.2	-9.8	7
EDQ 16063	I	A	LP	F	A	T	1.5	11.5	32.3	3.3	-11.7	6.8
EDQ 16064	I	A	LP	uk	SA	F	1.9	12.5	35.1	3.3	-10.7	8.1

EDQ 16065	I	A	LIP/LP	uk	A	F	0.7	9	25.8	3.3	-9.8	7.2
EDQ 16067	I	A	LIP/LP	uk	SA	C	2.2	10.3	28.7	3.3	-10.1	8.9
EDQ 16068	I	A	LIP/LP	F	A	Rib	2.9	13.7	38.5	3.3	-12.1	6.3
EDQ 16069	I	A	LIP/LP	F	A	H	2.2	11.9	33.1	3.2	-11.5	6.7
EDQ 16070	*I*	*A*	*LIP/LP*	*M?*	*A*	T	*0.6*	*10.5*	*30*	*3.3*	*-11.6*	*8*
EDQ 16072	I	A	LIP/LP	uk	SA	Rib	2.9	13.3	36.7	3.2	-12	5.7
EDQ 16074	I	A	LP	M?	A	F	3.3	13.3	37.1	3.2	-11.3	6.8
EDQ 16075	I	A	LP	F?	SA	F	1.1	9.3	26.4	3.3	-11.1	6.5
EDQ 16076	I	A	LIP/LP	F	A	T	5.2	15.8	43.1	3.2	-11.4	7.7
EDQ 16077	I	A	LP	F?	A	F	3	13.1	36.6	3.3	-10.5	7.9
EDQ 16078	I	A	LIP/LP	uk	uk	T	2	11.5	31.9	3.2	-12.7	6.7
EDQ 16079	I	A	LIP/LP	uk	A	Rib	3.2	12.6	35.1	3.2	-12.6	6.7
EDQ 16080	I	A	LIP/LP	F?	A	T	1.6	8.2	24.2	3.5	-14.7	6.5
EDQ 16081	I	A	LP	uk	A	T	3.1	14.1	39.1	3.2	-9.4	8.6
EDQ 16071	I	A	LIP/LP	F	A	F	2.5	8.2	23.1	3.3	-12	7.3
EDQ 16082	I	A	LP	F	A	F	5	10	27.5	3.2	-11.1	7.5
EDQ 16083	I	A	LP	uk	SA	Rib	10.7	16.4	44.6	3.2	-11	7.6
EDQ 16084	I	A	LIP/LP	F?	A	F	3.5	11.2	31.1	3.2	-11.1	7.3
EDQ 16085	I	A	LP	uk	SA	F	2.1	11	31.2	3.3	-11.7	6.5
EDQ 16086	I	A	LIP/LP	M	A	T	4	12.1	33.5	3.2	-11.9	6.5
EDQ 16087	I	A	LIP/LP	M	A	T	4	9.4	26.5	3.3	-12.4	7.3
EDQ 16089	I	A	LP	M	A	H	3.7	11.8	33	3.3	-10.8	8
EDQ 16091	I	A	LP	F	A	T	1.8	7.5	21.2	3.3	-10	7.6
EDQ 16092	*I*	*A*	LP	M	A	T	4.5	9.7	27.4	3.3	-9.1	9.2
EDQ 16093	I	A	LIP/LP	F?	A	T	3.8	11.6	32.3	3.2	-13	8.1
EDQ 16094	*I*	*A*	LIP/LP	F	A	T	5.2	11.2	31.3	3.3	-10.7	7.8
EDQ 16095	I	A	LIP/LP	uk	SA	F	5.7	10.1	27.8	3.2	-11.8	7.2
EDQ 16096	*I*	*A*	LIP/LP	F	A	T	5.6	10.6	29.5	3.3	-11.3	7.9
EDQ 16097	I	A	ECP	uk	SA	F	10.6	14.1	38.8	3.2	-21	4.2
EDQ 16098	*I*	*A*	LIP/LP	M	A	T	6.8	11.9	33.3	3.3	-11.4	7.9
EDQ 16099	I	A	ECP	F	A	F	8.6	12.6	35	3.2	-21.1	4.5

EDQ 16100	*I*	*A*	ECP	uk	SA	C	3.9	7.3	20.5	3.3	-19.4	4.9
EDQ 16101	I	A	LIP/LP	uk	SA	F	5.1	11.4	32.4	3.3	-13.7	6.6
EDQ 16102	*I*	*A*	LIP/LP	F?	A	F	3.2	11.7	32.6	3.2	-13.6	7.9
EDQ 16103	I	A	LP	uk	A	T	4.7	10.8	30.2	3.3	-13.8	7.9
EDQ 16104	*I*	*A*	LIP/LP	M?	A	T	6.3	12.6	35.6	3.3	-9.6	9
EDQ 16105	I	A	LIP/LP	uk	SA	Rib	10.5	8.5	23.8	3.3	-11.2	6.2
EDQ 16106	*I*	*A*	LIP/LP	uk	A	Rib	3.6	11.1	33.7	3.5	-13.7	6.9
EDQ 16107	I	A	LP	M	A	T	15.8	14.1	38.8	3.2	-10.2	8.1
EDQ 16108	*I*	*A*	LP	uk	A	F	3.8	11.8	32.7	3.2	-9.6	7.9
EDQ 17001	*I*	*A*	*LP*	*F?*	*A*	T	*2.4*	*5.2*	*16*	*3.6*	*-12.3*	*6.4*
EDQ 17002	*I*	*A*	LIP/LP	F	A	F	3.5	11.2	31.4	3.3	-11.5	6.7
EDQ 17003	*I*	*A*	LIP/LP	F	A	T	3.9	8.8	25.3	3.4	-13.5	6.6
EDQ 17004	*I*	*A*	LP	M	A	F	3.9	9.8	27.5	3.3	-10.2	6.8
EDQ 17005	*I*	*A*	LP	M	A	H	3.9	10.8	30	3.2	-8.4	8.3
EDQ 17006	*I*	*A*	LP	uk	A	F	5.8	9.3	26.2	3.3	-10.1	7.2
EDQ 17007	*I*	*A*	LP	F?	A	F	4.2	11.8	32.8	3.2	-9.7	7.7
EDQ 17008	*I*	*A*	LP	F	A	Rib	3.3	11.6	32.6	3.3	-11	7.4
EDQ 17010	*I*	*A*	LIP/LP	F	A	T	5.3	13	35.4	3.2	-11.1	6.9
EDQ 17011	I	A	LP	uk	A	H	3.4	9.6	26.9	3.3	-11.2	7.4
EDQ 17012	I	A	LIP/LP	M	A	Rib	5	14.8	41.6	3.3	-9.6	7.6
EDQ 17013	I	A	LIP/LP	M	A	T	5.5	11.7	32.4	3.2	-9.9	7.7
EDQ 17014	I	A	LIP/LP	F	A	Rib	7.8	12.6	35.5	3.3	-10.4	7.5
EDQ 17015	I	A	LIP/LP	M?	A	F	5.4	10.8	29.7	3.2	-9.6	7.2
EDQ 17016	I	A	ECP?	uk	A	F	3	11.2	30.7	3.2	-15.8	6.1
EDQ 17017	I	A	LIP/LP	uk	SA	F	5.3	10.9	30.2	3.2	-13.7	5.8
EDQ 17018	I	A	LIP/LP	F	A	F	3.5	9.8	27.1	3.2	-12.2	6.2
EDQ 17019	I	A	LIP/LP	uk	A	F	4.1	11	30.4	3.2	-9	7.7
EDQ 17020	I	A	LP	uk	SA	T	8.4	12.4	34.1	3.2	-11.7	6.5
EDQ 17021	I	A	LIP/LP	M	A	F	6	10.9	30.2	3.2	-11.9	8.2
EDQ 17022	I	A	LIP/LP	M	A	T	3.6	14.6	41	3.3	-10.2	7.2
EDQ 17023	I	A	LIP/LP	uk	SA	F	2.8	11.2	31.1	3.2	-12.7	7

EDQ 17024	I	A	LIP/LP	F	A	T	3.1	10.5	29.4	3.3	-13.5	5
EDQ 17025	I	A	LP	M	A	Fi	2.6	10.9	30.4	3.3	-12.3	6.3
EDQ 17026	I	A	LIP/LP	M	A	F	1.5	7.8	22.9	3.4	-13.3	8.3
EDQ 17027	I	A	LIP/LP	uk	SA	H	4.4	11.7	32.6	3.3	-12.8	6.2
EDQ 17028	I	A	ECP	M	A	F	4.2	11.4	31.8	3.3	-21	4.9
EDQ 17029	I	A	LIP/LP	M	A	H	3.2	9.1	25.9	3.3	-10.1	7.3
EDQ 17030	I	A	LP	uk	A	C	4	9.7	27.4	3.3	-10.5	7.8
EDQ 17031	I	A	LIP/LP	F	A	T	5.8	11.4	31.6	3.2	-11.7	6.6
EDQ 17032	I	A	ECP	M?	A	T	4.6	11	30.5	3.2	-20.4	5.8
EDQ 17033	I	A	ECP	uk	A	F	2.8	12.1	35.6	3.4	-21.3	4.7
EDQ 17034	I	A	ECP	M	A	F	5.1	11.7	33	3.3	-21.5	4.4
EDQ 17035	I	A	LIP/LP	M?	A	F	3.9	10.5	29.1	3.2	-11.8	8.6
EDQ 17036	*I*	*A*	*LIP/LP*	*M*	*A*	H	*1*	*10.3*	*29*	*3.2*	*-11.5*	*8.9*
EDQ 17038	I	A	LIP/LP	F?	A	F	4.3	14.8	41.5	3.3	-10.7	7.6
EDQ 17039	I	A	LP	uk	SA	T	4.5	13.6	38.5	3.3	-11.9	7
EDQ 17040	I	A	LP	uk	SA	C	5	15.5	43.6	3.3	-9.7	10.6
EDQ 17041	I	A	LP	uk	SA	C	3.5	14	39	3.3	-10.1	11.8
EDQ 17042	I	A	LP	uk	SA	C	5.1	14.6	40.8	3.3	-9	9.5
EDQ 17043	I	A	LP	F	A	Rib	3.6	12.8	35.8	3.3	-11.2	6.4
EDQ 17044	I	A	LIP/LP	F?	A	T	2.6	13.6	37.5	3.2	-9.7	7.5
EDQ 17045	I	A	LP	F	A	H	3.9	12.7	35.2	3.2	-11.9	7.6
EDQ 17046	I	A	LIP/LP	M	A	U	1.1	7.6	22.4	3.4	-12.1	7.2
EDQ 17047	I	A	LP	M?	A	Rib	2.9	13.7	39.4	3.4	-10.4	7.1
EDQ 17048	I	A	LP	M	A	Fi	6.6	14	38.6	3.2	-10.2	7.2
EDQ 17049	I	A	LP	uk	SA	F	3.8	12.4	34.6	3.3	-10.5	6.3
EDQ 17050	I	A	LP	uk	SA	T	11.3	15.4	43.3	3.3	-12.4	7
EDQ 17051	I	A	LP	uk	SA	T	3.8	13.1	35.8	3.2	-9.8	7.7
EDQ 17052	I	A	LIP/LP	uk	A	T	3.2	13.1	36.2	3.2	-10.3	7.7
EDQ 17053	I	A	ECP	uk	SA	T	1.8	11	31	3.3	-21.4	4.5
EDQ 17054	I	A	LIP/LP	F	SA	F	7.1	13.8	38.6	3.3	-11	7.6
EDQ 17055	I	A	LIP/LP	M?	A	F	1.5	9.3	26.8	3.4	-11	6.9

EDQ 17056	I	A	LIP/LP	F	A	Rib	3.5	11.9	33.6	3.3	-13	6.9
EDQ 17057	I	A	LIP/LP	uk	SA	C	4.3	15.3	42.9	3.3	-9.9	9.4
EDQ 17058	I	A	LIP/LP	F	A	Rib	6.1	15.9	44.9	3.3	-11	7.3
EDQ 17059	I	A	LIP/LP	F	A	T	2.9	14.1	39.1	3.2	-11.3	7.6
EDQ 17060	I	A	uk	uk	uk	Rib	1.2	9.7	27.4	3.3	-13.2	6.1
EDQ 17061	I	A	ECP	uk	A	T	5.7	12	33.4	3.2	-20.4	4.4
EDQ 17062	I	A	uk	F	A	T	2.7	14	38.7	3.2	-13.8	6.9
EDQ 17063	I	A	ECP	M?	A	Rib	5.8	15.6	43.1	3.2	-21.1	4.8
EDQ 17064	I	A	LP	M	A	H	2.5	14.7	41.8	3.3	-9.2	9
EDQ 17065	I	A	LP	F	A	F	3.6	12.3	35.1	3.3	-13.5	7.1
EDQ 17066	I	A	LP	uk	A	T	3.3	13.7	39.1	3.3	-11.5	7.2
EDQ 17068	I	A	LIP/LP	uk	A	C	1.6	9.1	25.4	3.2	-13.9	6.7
EDQ 17069	I	A	LP	uk	SA	T	3.1	12.5	35	3.3	-10	8.1
EDQ 17070	I	A	LP	M?	A	F	5.5	14.4	40.5	3.3	-11.2	8.4
EDQ 17071	I	A	LP	uk	SA	C	7	15.9	44.5	3.3	-10.7	7.2
EDQ 17072	I	A	LIP/LP	uk	SA	F	4.2	14.4	40.4	3.3	-11.6	7.3
EDQ 17073	I	A	LIP/LP	uk	SA	T	5	14.9	41.8	3.3	-9.9	7.9
EDQ 17074	I	A	LIP/LP	uk	SA	Rib	6	8.5	23.8	3.3	-9.7	8.3
EDQ 17075	I	A	LIP/LP	M?	A	F	7.6	14	39.2	3.3	-12.1	6.3
EDQ 17076	I	A	LP	uk	SA	R	7.3	12.7	34.6	3.2	-10.1	8.1
EDQ 17078	I	A	ECP	uk	A	T	3.3	11.1	30.5	3.2	-19.7	5
EDQ 17079	I	A	LIP/LP	uk	SA	C	3.7	15.8	44.6	3.3	-12	8.2
EMII 16021	C	A	ECP	M	A	T	2.7	11.5	32.4	3.3	-17.3	12.9
FE 16001	I	A	LIP	M	A	F	5.3	12.3	35.3	3.4	-11	7.3
FE 16002	I	A	ECP	F	A	Rib	4.3	10.8	31.1	3.4	-15.9	8.3
FE 16003	I	A	LIP	M	A	U	3.5	12.8	36.3	3.3	-10.3	8.6
FE 16004	I	A	ECP	M	A	F	11.9	11.7	33	3.3	-14.8	7.5
FE 16006	I	A	ECP	F	A	H	2.6	10.8	30	3.2	-16.2	6.8
FE 16007	I	A	ECP	M	A	Rib	3.4	12	37.3	3.6	-16.8	8.3
FE 16008	I	A	LIP	F	A	Rib	2.7	13	36.5	3.3	-10.9	8.2
FE 16010	I	A	ECP	uk	SA	R	12.6	15	41.8	3.3	-20.5	4.5

FE 16011	I	A	ECP	M?	A	Rib	7.8	14.6	40.8	3.3	-21	4.5
FE 16012	I	A	ECP	M	A	H	11.2	15.2	42.9	3.3	-14.7	7
FE 16009	I	A	ECP	uk	A	F	4.3	8.9	24.7	3.2	-15.7	5.8
LA 18001	I	A	LP	uk	A	Rib	17.7	18.6	51.9	3.2	-13.1	5.6
LA 18002	I	A	uk	F	A	F	4.1	13.9	38.3	3.2	-13.1	4.1
LA 18003	I	A	LIP	F?	SA	H	4.3	10	28.1	3.3	-14.3	5.4
LA 18005	I	A	LIP/LP?	uk	A	T	2	9.2	27.3	3.5	-14.2	5.7
LA 18006	I	A	uk	uk	A	U	3.2	13.3	37	3.3	-16.1	5.5
LA 18007	I	A	Uk	M	A	T	1.4	5.6	16.4	3.4	-9.8	5.8
LA 18008	I	A	LIP/LP?	F?	A	U	6	11.9	34.3	3.4	-11.8	5
LA 18009	I	A	LIP	F	A	T	9.3	15.7	43.5	3.2	-11.4	6
LA 18010	I	A	LIP	uk	A	C	5.4	15.1	41.9	3.2	-12.7	7.4
LA 18011	I	A	ECP	M?	A	F	1.4	7.8	22.3	3.3	-14.9	4
LA 18012	I	A	ECP	uk	A	H	2.8	11.8	33	3.3	-15	4.2
LA 18013	I	A	uk	F	A	F	2.8	11.8	33.2	3.3	-12.5	4.9
LA 18014	I	A	ECP	F	A	S	3.1	14.6	42.6	3.4	-17	4.5
LA 18015	I	A	LIP/LP?	M?	A	C	10.9	14.1	39.2	3.2	-12.5	9.2
LA 18016	I	A	uk	F	A	F	2.9	8	23.2	3.4	-15.3	4.6
LA 18017	I	A	uk	M?	A	T	2.6	8.2	23.1	3.3	-11.3	9.4
LA 18018	I	A	uk	M	A	F	1.8	13.3	39.1	3.4	-12.3	5.8
LA 18021	I	A	LP	uk	A	F	6	12.6	36.2	3.4	-11.3	5.6
LA 18022	I	A	LP	uk	A	Rib	2	8.8	25.2	3.3	-19.3	4.1
LA 18023	I	A	ECP	F?	A	T	6.4	9.7	27.3	3.3	-18	4.2
LA 18024	I	A	ECP	uk	SA	T	3	9.6	26.9	3.3	-17.6	4
LA 18025	I	A	ECP	uk	SA	T	3.7	14.5	30.9	3.3	-14.6	4.8
LA 18026	I	A	ECP	uk	A	T	3.2	10.1	28.6	3.3	-16.8	4.6
LCh 16060	I	A	ECP	M	A	C	2.7	9.4	26.9	3.3	-19	7.6
LCo 17080	C	L	LIP	F	A	Fi	1.5	15.7	43.8	3.3	-11.5	9.7
LCo 17081	C	L	LIP	uk	SA	Rib	1.6	14.4	41.8	3.4	-10.5	11.3
LCo 17082	C	L	LIP	uk	SA	C	1.5	15.2	43.4	3.3	-11.8	13.6
LCo 17083	C	L	LIP	F	A	Rib	1.7	14.6	41.7	3.3	-12.3	9.6

LCo 17084	C	L	LIP	M	A	Rib	2.7	15.3	42.5	3.2	-10.1	12
LCo 17085	C	L	LIP	M	A	Rib	2.2	15	42	3.3	-10.5	9.2
LCo 17086	C	L	LIP	F	A	Rib	2.2	14.5	40.4	3.2	-11.3	11
LCo 17087	C	L	LIP	uk	SA	Rib	1.6	15.5	43.2	3.2	-10.8	12.9
LCo 17088	C	L	LIP	uk	SA	Rib	1.6	14.9	41.5	3.2	-12.1	11.2
LCo 17089	C	L	LIP	uk	SA	F	1.8	14.6	41.4	3.3	-12.2	9.7
LCo 17090	C	L	LIP	uk	SA	Rib	2.5	15.7	43.8	3.2	-8.7	14.7
LCo 17091	C	L	LIP	uk	SA	U	1.6	15.6	44.6	3.3	-10.4	11.2
LL 17093	I	L	LP	F	A	Rib	1.5	15.4	43.3	3.3	-12	8.8
Malt 16013	I	A	LIP	uk	A	T	3.8	14.3	40	3.3	-11	7.2
Malt 16014	I	A	LIP	M	A	F	1.6	13	36.5	3.3	-10.1	8.1
Malt 16015	I	A	LIP	F?	A	Rib	5.2	15.6	44.7	3.3	-11.8	7.2
Pa 16046	C	L	ECP	F	A	F	5.4	15.1	42.2	3.2	-16.9	9.8
Pa 16047	C	L	ECP	F?	A	C	4.4	15.4	42.3	3.2	-16.3	14.5
Pa 16048	C	L	ECP	F	A	C	13.5	15.6	43	3.2	-18.7	10.9
PdI 16022	I	A	ECP	F?	A	F	2.5	15.4	43.2	3.3	-15.7	6.4
PdI 16023	I	A	ECP	uk	A	F	4.7	15.1	42.7	3.3	-15.8	6.2
PdI 16024	I	A	ECP	M?	A	F	1.6	11.4	32.5	3.3	-19.8	5.6
Po 16061	I	A	ECP	M	A	R	3.6	15.1	42.1	3.3	-20.4	5.4
Po 16062	I	A	ECP	M?	A	C	6.5	16	45	3.3	-20.4	5.7
Q17092	I	L	LP	F	A	F	1.5	16.9	47.7	3.3	-9.8	9.4
SB1 16056	C	A	ECP	uk	A	F	4.9	13.8	39.5	3.3	-18.2	10.9
SB1 16057	C	A	ECP	M?	A	Rib	9.9	13.4	38.1	3.3	-14.6	14.8
StC 16049	I	A	ECP	M	A	Fi	7.1	8.9	24.8	3.2	-14.7	5.8
StC 16050	I	A	ECP	uk	A	F	3.5	12.6	34.7	3.2	-19.3	5
StC 16051	I	A	ECP	uk	A	F	2	12.9	36.1	3.3	-18.6	5.9
StC 16053	I	A	ECP	M?	A	C	3.2	12.4	35	3.3	-19.5	5
StC 16054	I	A	ECP	uk	A	F	5.4	11.6	32.3	3.2	-19.1	5.2
StC 16055	I	A	ECP	uk	A	F	2.8	8.7	25.1	3.4	-19.4	4.3
VA 16059	I	A	LP	uk	A	C	4.3	13	37.7	3.4	-11.4	11.4
VH 17128	I	L	uk	uk	SA	Rib	16.1	16.3	45.4	3.3	-15.3	5.3

VH 17129	I	L	uk	uk	SA	Rib	9.1	15.4	42.3	3.2	-12.3	7.8
VH 17130	I	L	uk	uk	SA	C	10.4	15.4	44.1	3.3	-12.2	8.8
VH 17131	I	L	uk	M	A	H	6	14.6	40.8	3.3	-12.9	6
VH 17132	I	L	uk	M?	A	H	8.3	14.4	40.3	3.3	-12.1	8.6
VH 17133	I	L	ECP	uk	A	T	9.9	15.2	43.5	3.3	-18.8	7.6
VH 17134	I	L	LIP	uk	SA	Rib	17.2	15.4	42.3	3.2	-13	7.2
VH 17135	I	L	uk	uk	SA	C	7.2	14.7	40.7	3.2	-10.5	9.5
VH 17136	I	L	ECP	uk	SA	Rib	16.5	15.8	44.2	3.3	-12.9	7.1
VH 17137	I	L	ECP	F?	A	C	4.4	13.1	36.5	3.3	-18.7	7.2
VH 17138	I	L	LIP	uk	SA	Rib	9.8	14.7	41.5	3.3	-11.9	8
VH 17139	I	L	LIP	uk	A	T	5.2	14	40.4	3.4	-13.4	6.7
VH 17140	I	L	LIP/LP	uk	SA	Rib	12.9	14.6	41.7	3.3	-14.3	5.7
VH 17141	I	L	ECP	M	A	T	13.3	15.4	42.9	3.3	-11.5	9.1
VH 17142	I	L	uk	uk	SA	C	9.8	15.2	43.6	3.4	-10.6	9.4
VH 17143	I	L	LIP/LP	uk	SA	C	12.2	14.8	42.6	3.4	-14.8	5.1
VH 17144	I	L	uk	uk	SA	Rib	17.3	15.3	42.6	3.2	-13.6	8.8
VH 17145	I	L	uk	uk	SA	Rib	7.8	14.7	42.5	3.4	-13.1	7.1
VH 17146	I	L	uk	M	A	Rib	12.6	14.6	41.9	3.3	-11	8.7
VH 17147	I	L	uk	uk	SA	C	10.8	14.9	42.5	3.3	-13.5	9
VH 17148	I	L	uk	uk	SA	T	10.3	14.5	39.9	3.2	-12	7.9
VH 17149	I	L	uk	uk	SA	C	2.3	13.6	40.1	3.5	-13.2	9.3
VH 17150	I	L	uk	M	A	Rib	5.5	9.3	26.4	3.3	-10.9	8.1
VH 17151	I	L	uk	uk	SA	C	1.8	12.5	37.4	3.5	-14.2	8.1
VH 17152	I	L	uk	uk	SA	C	11.1	15.4	43.7	3.3	-11.4	9.5
VH 17153	I	L	ECP	uk	SA	Rib	15	15.8	44.1	3.2	-15.1	6.3
VH 17154	I	L	uk	uk	SA	Rib	14.1	16.5	46.1	3.3	-11.4	10
VH 17155	I	L	uk	F	A	Rib	3.1	15.4	43.7	3.3	-13	6.3
VH 17156	I	L	uk	uk	SA	C	3.1	10.7	30	3.3	-11.6	10.7
VH 17157	I	L	LIP/LP	M	A	Rib	13.8	13.8	38.9	3.3	-10.5	8.4
VH 17158	I	L	LIP	uk	SA	Rib	13.9	16.7	46.1	3.2	-12.5	6.2
VH 17159	I	L	uk	uk	SA	Rib	15.4	14.5	39.8	3.2	-15	5.3

VH 17160	I	L	uk	uk	SA	C	14.4	15.5	43.7	3.3	-10.7	9.4
VH 17161	I	L	LIP	uk	SA	C	3.2	5.8	17	3.4	-13.2	6.5
VH 17162	I	L	LIP	uk	SA	Rib	11.6	13.9	38.4	3.2	-13	5.3
VH 17163	I	L	LIP	uk	SA	Fi	8.9	15.8	44.5	3.3	-12	7
VH 17164	I	L	LIP	uk	SA	H	2.7	12.8	36.1	3.3	-13.6	7.5
VH 17165	I	L	LIP	F	A	Rib	12.8	13.6	37.5	3.2	-12.1	8.5
VH 17166	I	L	uk	uk	SA	H	11.7	15.8	43.8	3.2	-12.3	7
VH 17167	I	L	ECP	M?	A	Rib	1.7	7.6	21.5	3.3	-13.2	6.3
VH 17168	I	L	uk	M?	A	C	5.5	13.6	37.7	3.2	-12.9	9
VH 17169	I	L	ECP	uk	A	C	3	11.2	31.2	3.2	-12.1	6.1
VH 17170	I	L	uk	uk	SA	Rib	16.3	15.6	43.4	3.2	-9.4	9
VH 17171	I	L	uk	uk	SA	Rib	8.5	14.9	41.7	3.3	-12.6	5.9
VH 17172	I	L	uk	F	A	Rib	15.2	14.6	40.5	3.2	-12.2	7.9
VH 17173	I	L	LIP	uk	SA	H	7	15.3	43.1	3.3	-14.9	5.2
VH 17174	I	L	ECP	uk	SA	C	3.8	14.8	42.4	3.3	-17.7	7.7
VH 17175	I	L	uk	uk	SA	F	6	15.9	45	3.3	-12.9	9.1
VH 17176	I	L	LIP	uk	SA	F	10	15	41.3	3.2	-13.9	8.1
VH 17177	I	L	LIP	uk	SA	Rib	9	14.5	39.9	3.2	-11.6	7
VH 17178	I	L	uk	uk	SA	R	12.6	16.5	46.2	3.3	-12.7	7.1

***Table 1**: Stable carbon ($\delta^{13}C$ [‰ AIR]) and nitrogen ($\delta^{15}N$ [‰ VPDB]) results for human bone collagen samples.*
[1]Setting: C = Coastal, I = Inland.
[2]Valley: A = Aconcagua Valley, L = La Ligua Valley.
[3]Temporal: = ECP = Early Ceramic Period, LIP = Late Intermediate Period, LIP/LP = Terminal Late Intermediate Period, LP = Late Period.
[4]Sex: M = male, M? = probable male, uk = undetermined, F? = probable female, F = female.
[5]Age: A = adult, SA = subadult
[6]Bone Sample: C = cranial bone, F = femur, Fi = fibula, H = humerus, Rib = rib, S = scapula, T = tibia, U = ulna.

Sample	Setting[1]	Valley[2]	Temporal[3]	Sex[4]	Age	Collagen Yield (% wt)	%N	%C	C:N	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
FE 16005	*I*	*A*	*LIP*	*F*	*Adult*	*0.2*	*.*	*.*	*.*	*.*	*.*
StC16052	*I*	*A*	*ECP*	*M?*	*Adult*	*1.8*	*3.3*	*10.2*	*3.6*	*-19.5*	*4.0*
VA16058	*I*	*A*	*LP*	*uk*	*Sub-adult*	*1.4*	*1.6*	*5.2*	*3.9*	*-16.0*	*4.2*
EDQ16066	*I*	*A*	*LIP/LP*	*F*	*Adult*	*1.1*	*0.6*	*3.3*	*6.9*	*-25.0*	*-2.8*
EDQ16073	*I*	*A*	*LP*		*Sub-adult*	*0.7*	*0.8*	*5.0*	*7.2*	*-13.2*	*0.7*
EDQ16088	*I*	*A*	*LIP/LP*	*uk*	*Adult*	*1.1*	*1.8*	*6.7*	*4.3*	*-14.3*	*3.9*
EDQ16090	*I*	*A*	*ECP*	*F*	*Adult*	*1.2*	*0.5*	*1.9*	*4.3*	*-21.5*	*-1.3*
EDQ17009	*I*	*A*	*LP*	*F*	*Adult*	*1.0*	*0.6*	*2.6*	*5.0*	*-21.4*	*0.2*
EDQ17037	*I*	*A*	*LP*	*uk*	*Adult*	*0.8*	*0.4*	*1.8*	*4.9*	*-25.6*	*-1.7*
EDQ17067	*I*	*A*	*LP*	*uk*	*Sub-adult*	*0.5*	*1.2*	*8.8*	*8.4*	*-23.3*	*4.3*
EDQ17077	*I*	*A*	*LP*	*uk*	*Sub-adult*	*0.1*	*1.1*	*6.1*	*6.2*	*-21.4*	*3.5*
LA18004	*I*	*A*	*uk*	*uk*	*Adult*	*1.0*	*0.8*	*2.8*	*4.4*	*-16.3*	*2.5*
LA18019	*I*	*A*	*LIP/LP?*	*F?*	*Adult*	*0.8*	*7.2*	*22.7*	*3.7*	*-15.2*	*3.3*
LA18020	*I*	*A*	*ECP*	*M?*	*Adult*	*0.3*	*1.1*	*4.9*	*5.0*	*-20.4*	*2.1*
LA18027	*I*	*A*	*ECP*	*F*	*Adult*	*1.7*	*0.7*	*2.6*	*4.0*	*-13.3*	*3.0*

Table 2: *Stable carbon ($\delta^{13}C$ [‰ $_{AIR}$]) and nitrogen ($\delta^{15}N$ [‰ $_{VPDB}$]) results for human bone collagen samples for samples that were excluded from further analysis due to failure to satisfy collagen quality criteria.*

[1]Setting: C = Coastal, I = Inland.

[2]Valley: A = Aconcagua Valley, L = La Ligua Valley.

[3]Temporal: = ECP = Early Ceramic Period, LIP = Late Intermediate Period, LIP/LP = Terminal Late Intermediate Period, LP = Late Period.

[4]Sex: M = male, M? = probable male, uk = undetermined, F? = probable female, F = female.

Resource	Context	*n*	$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
			Mean	SD	Max	Min	Mean	SD	Max	Min
Fauna										
Camelid	Archaeological	6	-19.5	0.6	-18.6	-20.2	5.0	0.9	6.4	4.0
Camelid (this study)	Archaeological	12	-19.6	2.7	-11.7	-21.5	5.2	1.8	8.7	1.7
Degu (this study)	Archaeological	3	-21.2	1.0	-20.5	-22.4	4.1	1.6	5.6	5.6
Lacustrine (coast)	Archaeological	2	-22.9	0.8	-22.3	-23.4	5.2	2.6	8.9	5.2
Lacustrine (inland)	Archaeological	1	-16.0				2.1			
Marine mammal	Archaeological	1	-11.7				20.2			
Marine Fish	Modern	5	-13.7	1.6	-11.4	-15.5	16.7	2.4	18.5	12.7
Marine Fish (this study)	Archaeological	2	-12.6	0.5	-12.3	-12.9	15.9	2.2	17.4	17.4
Marine Molluscs	Modern	4	-15.3	1.7	-13.2	-17.2	16.0	1.5	17.6	14.2
Flora										
Marine Algae	Modern	2	-15.7	2.3	-14.0	-17.3				
Marine Algae (this study)	Modern	3	-16.0	2.0	-14.3	-18.1	11.4	4	11.8	11.0
C_3 wild vegetation	Modern	14	-26.6	2.9	-21.0	-30.5				
C_3 wild vegetation (this study)	Modern	9	-27.1	3.1	-24.1	-33.1	-0.2	4.8	7.9	-7.1
C_3 cultigens	Modern	6	-26.6	1.6	-24.7	-29.3				
C_4 cultigens	Modern	1	-11.2							
CAM plants. (this study)	Modern	6	-13.3	1.1	-12.0	-14.9	4.6	3.4	7.8	-0.6

Table 3: Summarised stable carbon and nitrogen isotope values for Central Chilean fauna and flora (not adjusted for Suess effect) from this study and previously published data, adapted from Falabella et al. (2007).

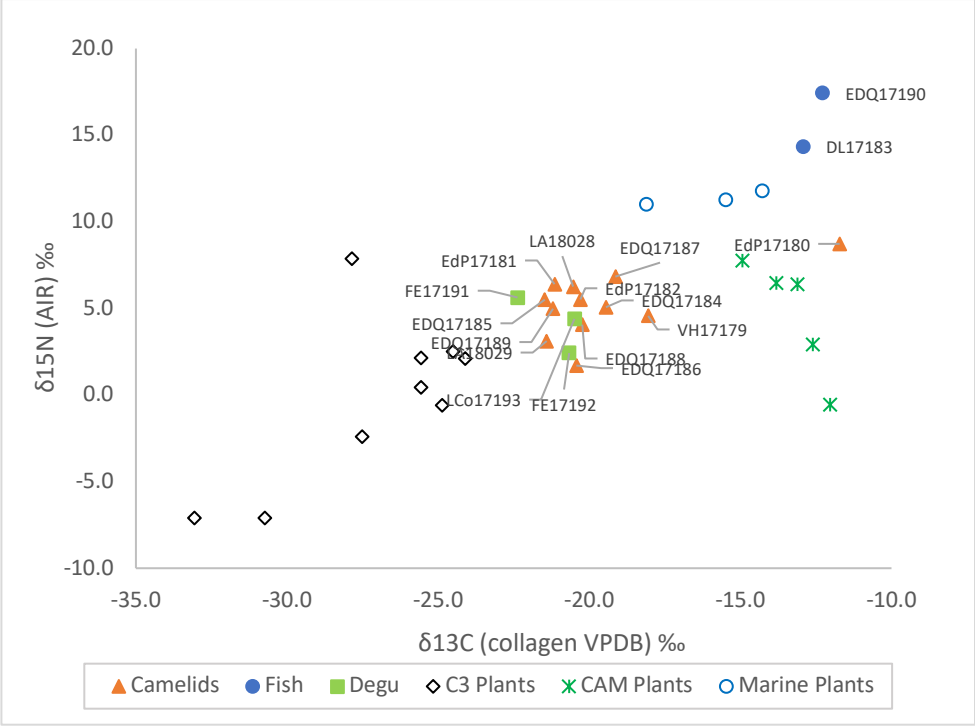


***Figure 1**: Plot of stable carbon and nitrogen isotopic results from botanical samples and bone collagen of archaeological faunal samples from sites included in this study. Faunals samples that were directly associated with a particular burial have been labelled with the burial code. VH = Valle Hermoso. EdP = Escuela de Placilla. FE = Fundo Esmeralda. LCo = Los Coiles 136. EDQ = Estadio de Quillota. DL = Dunos de Longotomá.*

CHAPTER 5: MAIZE AND DENTAL HEALTH: THE IMPACT OF AGRICULTURAL TRANSITION IN THE PRE-COLUMBIAN ACONCAGUA AND LA LIGUA VALLEYS OF CENTRAL CHILE

1. Introduction

The agricultural revolution is one of the major transitions in human history. The shift from hunting and gathering to agricultural subsistence economies is correlated with population growth, higher fertility, and arguably increased social complexity (Bandy 2005; Bocquet-Appel and Naji 2006). However, this transition often initially narrowed the availability of resources to heavy reliance on one or a limited number of crops, resulting in a carbohydrate-rich diet of reduced nutritional value, and is accompanied by increased sedentism and urbanisation which can create poorer standards of sanitation and an increase in infectious diseases. Palaeopathological reviews of the effects of the agricultural transition on human health, particularly in the New World, have found a general pattern of a decline in physiological health when interpreted from the prevalence of pathological lesions in the skeleton (Armelagos et al. 1991; Cohen and Armelagos 2013; Emerson et al. 2005; Larsen 1995). In a bioarchaeological context, dental pathologies, such as carious lesions, ante-mortem tooth loss (AMTL) and periapical cavities (a term which includes dental abscesses as well as other lesions in the periapical region), in particular, can provide a useful indication of subsistence strategies and changes in dietary patterns (Hillson 2001; Roberts and Manchester 2005).

The oral cavity is enormously important to human health, wellbeing, and survival. It is the entry point for such essentials as food, water, and air. Teeth interact directly with the environment, and moreover, with the foods a person eats. They provide a physical mechanism for processing food into a digestible state from which the body derives essential nutrition. The composition and consistency of food interacts both chemically and physically with the teeth, as well as determining the microorganisms present in the mouth (Gibbons 2012; Humphrey 2014; Moynihan 2001). The development of dental pathologies and other conditions, such as dental caries, ante-mortem tooth loss and periapical cavities, can contribute to inadequate nutrition by impairing the efficiency of chewing or causing a decrease in appetite due to

discomfort (Sheiham and Steele 2001). Poor dental health can consequently have an impact on the overall health and mortality rates of a population, which, in turn, is influenced by diet (Hillson 2008; Lukacs 2012). Indeed, the oral cavity plays and important role not only in nutrition, but in systemic health more broadly. Clinical research increasingly recognises oral health as a key indicator of general health, with poor oral status linked to cardiovascular disease, diabetes, and other systemic conditions (Peres et al. 2019; Watt et al. 2019). Unlike bone, tooth enamel lacks the ability to remodel, and teeth are generally well preserved in archaeological material. Thus, teeth and the study of dental palaeopathology, provide a valuable source of information regarding diet, subsistence, health and cultural behaviours in past populations (Hillson 2001; Lukacs 1989).

A clear relationship has been demonstrated between an increase in dental pathologies and the adoption of agriculture (e.g. Cohen and Armelagos 1984; Karsten et al. 2019; Smith and Betsinger 2019; Steckel and Rose 2002; Temple and Larsen 2007; Turner 1979). The inclusion of fermentable carbohydrates as dietary staples associated with this transition generally led to a rise in conditions such as dental caries, periapical cavities and AMTL (Karsten et al. 2019; Leverett 1982; Rowe 1975). This pattern has similarly been noted in the New World regarding maize agriculture in particular (e.g. Larsen 1984) and has also been observed in populations of Northern Chile (Alfonso et al. 2007; Kelley et al. 1991; Watson et al. 2010). Recent studies further support these findings, indicating higher caries rates associated with maize consumption in prehistoric populations (Karsten et al. 2019; Smith and Betsinger 2019). In both the arid and the semi-arid regions of Northern Chile, greater frequencies of dental pathologies have been linked to agricultural diets during the Middle Horizon period (Hubbe et al., 2012) and among the Diaguita culture (Rosado and Vernacchio-Wilson 2006). However, Central Chile, which lies towards the southern periphery of intensive pre-Columbian maize agriculture in the Americas, is largely underrepresented in palaeopathological literature.

More recently, the paradigm of dental health as a proxy for subsistence pattern has been challenged as oversimplistic and failing to consider the complex multifactorial pathogenesis of dental pathologies (Marklein et al. 2019). Other factors which can cause an increased susceptibility to dental pathologies

include the cariogenic potential of local resources and food preparation methods (Powell 1985; Tayles et al. 2009), the environment, and physiological differences relating to sex (Lukacs and Largaespada 2006). Both modern clinical research and palaeopathological studies have demonstrated that females have a higher susceptibility than males to poorer oral health, particularly dental caries and AMTL (Haugejorden 1996; Lukacs 2011a; 2011b; Lukacs and Thompson 2008). In an archaeological setting, higher rates of dental caries in females have often simply been interpreted a sex-based division in diet (Larsen, 1997; Hillson, 2008). However, there are other important factors relating to sex that can also predispose females to poorer oral health, such as earlier eruption of permanent dentition, saliva biochemistry and flow rate, and hormonal differences (Lukacs and Largaespada 2006). The impact of these pathogenic factors may be further compounded by demographic changes that occurred around the transition to agriculture, which often saw increased population sizes and fertility rates (Bocquet-Appel and Naji 2006).

The river valleys of Central Chile were a hub for intensive pre-Columbian maize production, and home to some of the southernmost agriculturalists in the Americas. The transition to maize agriculture occurred around cal AD 600-800 in this region (Swift in prep). Dietary stable isotope ($\delta^{13}C$ and $\delta^{15}N$) analysis of human bone collagen from sites along the La Ligua and Aconcagua Valleys has demonstrated a diachronic shift from C_3 resources, including wild plants and wild camelids supplemented with some early cultigens such as quinoa (*Chenopodium quinoa*), to the introduction and intensification of maize agriculture with an increasing dietary reliance on this C_4 plant resource over time. Maize starch is known to be cariogenic (Horton et al. 1985). Raw, yellow corn contains about 18.7g of carbohydrates, of which about 6.3g are sugars, primarily sucrose, per 100g (U.S. Department of Agriculture 2019). However, these concentrations can vary greatly with processing or preparation methods, as well as by the variety of corn (Prasanthi et al. 2017), which, in turn, can also impact cariogenicity of the foodstuff.

This article aims to present new dental health data, specifically dental caries, AMTL and peri-apical cavities, for the pre-Columbian populations of the La Ligua and Aconcagua Valleys of Central Chile (ca. 300 BC – AD 1536). Patterns of these lesions are interpreted alongside existing dietary stable isotope data to explore the

relationship between diet, specifically maize consumption, and these indicators of oral health. Furthermore, this data will also be examined between the sexes. The availability of isotopic data and biological profiles for the individuals comprising the sample from the Aconcagua and La Ligua Valleys presents the opportunity to explore the relationship between the direct dietary proxy for maize consumption provided by stable isotope data and the prevalence of dental pathologies, including caries, AMTL and periapical cavities. It is expected there will be an increase in the dental pathologies, caries, AMTL and periapical cavities with the increasing inclusion of maize in the diet. It is also expected that females will be affected by a higher rate of caries and AMTL than males, and that this difference between the sexes will increase after the adoption of maize agriculture due to a potential coeval increase in fertility.

2. Background

2.1 Study Area

The two major river valley systems of the study area, the Aconcagua and La Ligua Valleys, are geographically diverse, extending from the upper basin of the Aconcagua in the east, across the inland valley, through the coastal mountain range and descending to the Pacific coast in the west (Figure 1). The region is subject to a Mediterranean climate experiencing dry summers and cool winters with moderate rainfall. Notwithstanding the general late Holocene climate variability and the influence of El Niño Southern Oscillation, this regional climate has remained relatively similar over the last 3000 years (Jenny et al. 2002; Villa-Martínez et al. 2003; Villagrán and Varela 1990).

The last ca. 2000 years in the region saw major social, cultural and technological developments, not least of which included changes in subsistence strategies and lifeways (Table 1). The transition to maize agriculture occurred around ca. AD 450-600 in this region, with an intensification around ca. AD 1000-1200 (Falabella et al. 2016a; Swift et al. 2022; Swift et al. 2017). Different dietary practices broadly coincide with recognised temporal periods.



Figure 1: Map of the study area, showing location of sites along the Aconcagua and La Ligua Valleys from which dental material was examined for this study.

Dates	Temporal Period	Cultural Groups	Description
ca. 300 BC – AD 1000/1200	Early Ceramic (ECP)	Initial Ceramic Communities (ca. 300BC–AD200) Bato (ca. AD200–1000) Llolleo (ca. AD400–1200)	• Ceramics appear in the archaeological record. • Small, heterogeneous groups coexisted with different subsistence practices, material culture, funerary practices and settlement patterns • The Initial Ceramic Communities (ICC) relied upon wild (C_3) plants, although quinoa has been recorded at some sites (Quiroz and Belmar 2004; Sanhueza and Falabella 1999). • The Bato are primarily located along the coast, with limited inland contexts (Ávalos and Saunier 2011) (Ávalos 2007; Hermosilla 1994). They retained territorial mobility as hunter-fisher-gatherers relying upon marine resources, wild camelids and wild (C_3) plants (Ávalos and Saunier 2011; Carmona et al. 2001; Rivas and Gonzalez 2008). Archaeobotanical remains of quinoa and an endemic variety of maize at some inland sites also indicates incipient use or access to some early domesticates (Ávalos 2005; Planella and Tagle 2004). • The Llolleo were more sedentary and with a greater focus on cultigens. They occupied the middle and upper sequences of the river valleys in small, self-sufficient groups (Falabella et al. 2016a). Both wild and cultivated plants, as well as guanaco (*Lama guanicoe*) bones have been recorded at Llolleo sites (Planella and Tagle 2004). Cultigens include maize, quinoa, beans (*Phaseolus sp.*), squash (*Curcurbita sp.*), and gourds (*Lagenaria sp.*) (Planella et al. 2014; Planella and Tagle 2004; Sanhueza et al. 2003).
ca. AD 1000/1200 – 1400/1450	Late Intermediate (LIP)	Aconcagua	• Settlements located along river valley terraces, with crop fields, spaces for processing food and producing lithics and pottery close to habitation areas. • Preferentially, but not exclusively, inhabited the inland valley, rather than the coast. • Increased dependence upon maize is demonstrated by a ubiquity of the resource at sites, an increase in the size of maize kernels and a greater diversity of varieties (Belmar and Quiroz, 2003b; Planella et al. 2014 in Falabella et al., 2016). • An increase in the size and variety of beans, and the grain size of quinoa provide further evidence for the intensification of agriculture during this period (Planella et al. 2013). • Camelids were also partially domesticated and there was an increased reliance on guanaco meat (Becker 1994; Sanhueza and Falabella 2010; Tykot et al. 2009).
ca. AD1400 – 1536	Late (LP)	Aconcagua-Inka Diaguita	• Inka influence expanded into the region. • Ceremonial, defensive and administrative imperial structures established at strategic points along the river valleys and longitudinal roads (Coros and Coros 1999), integrating the area into the southern frontier of the Inka empire. • Local cultures, including the Aconcagua and Diaguita, persisted into the Late Period (LP), but were partially acculturated, with signs of Inka influence in their material culture. • Social hierarchy organised around local leaders, *caciques*, and clustered settlements. • Intensification of maize agriculture and an increase in camelid domestication and mining (Uribe and Sánchez 2016).

Table 1: Summary of archaeological periods and cultural phases relevant to the Aconcagua and La Ligua river valleys of Central Chile (adapted from Falabella et al. (2016b)).

2.2 STABLE ISOTOPES

Maize is a C_4 plant, meaning it utilises the Hatch-Slack photosynthetic pathway, and has a more elevated stable carbon isotope signature, compared with all C_3 plants. Stable carbon isotope ($\delta^{13}C$) analysis is, therefore, a helpful way for detecting the introduction and increasing reliance on maize as a staple crop. Recent $\delta^{13}C$ analysis of human bone collagen from sites along the La Ligua and Aconcagua Valleys has demonstrated considerable variability in dietary practices over time, from a total dependence on C_3-based resources to heavy reliance on C_4 resources (Swift et al. 2017; Swift et al. in prep.). A marked increase in $\delta^{13}C$ values from the Early Ceramic Period to the Late Intermediate Period and again to the Late Period indicates the growing importance of maize as a primary crop over time. These findings indicate a transition from foraging for wild C_3 resources to farming C_4 maize, which increases from the Early Ceramic Period (c. 300 BC–AD 1000/1200) and intensifies into the Late Intermediate (c. AD 1000/1200–1400) and Late Periods (c. AD 1400–1536).

Radiocarbon dates from Valle Hermoso in the La Ligua Valley and Estadio de Quillota in the Aconcagua Valleys point to an earlier (339–196 cal BC to cal AD 128–339 [OxA V-2735-19 and V-2737-44]) and a later (cal AD 1276–1379 to cal AD 1413–1458 [UCIAMS 206835 and OxA V-2735-18]) phase of use at these large cemetery sites (Swift et al. 2022). These earlier and later phases of use are significantly correlated with different dietary patterns and the shift to higher $\delta^{13}C$ and $\delta^{15}N$ values ($\delta^{13}C$ $p<0.001$, $\delta^{15}N$ $p<0.001$) in the latter phase of use (Chapter 4). Thus, the isotopic data also support two distinct dietary phases of an earlier, predominantly C_3-based diet and later broadly distributed C_4-based diets.

At inland sites, $\delta^{13}C$ values ranged from -21.5‰ to and -8.4‰ (Chapters 2 and 4). The earlier diet was based largely on C_3 plants with $\delta^{13}C$ values at the lower end of this range. This was followed by an incipient use of maize and mid-range $\delta^{13}C$ values before progressing to a heavily maize-dependent diet represented by elevated $\delta^{13}C$ values. People from coastal sites had mixed terrestrial-marine diets which included low-

trophic-level marine resources. These diets can be distinguished by more elevated $\delta^{15}N$ values. Even within the coastal diets, a shift can be seen between the pre- and post-maize groups with an increase in $\delta^{13}C$ values that occurs from the Early Ceramic Period to the Late Intermediate Period ($\delta^{13}C$ values from -18.2‰ to -13.9‰ for the marine diet group and -12.3‰ to -10.1‰ for the marine-C_4 diet).

2.3 DENTAL PATHOLOGIES

2.3.1 Dental Caries

Dental caries is one of the most prevalent chronic, infectious diseases that affects humans worldwide (Langsjoen 1988; Jayadevan et al. 2019). Diet, the oral microbiome and the flow of saliva are all factors which influence the formation of dental caries. Diets richer in fermentable carbohydrates will result in a higher frequency of dental caries in the presence of sugar and starch fermenting oral microorganisms, such as *Lactobacillus acidophilus* and *Streptococcus mutans* (Hillson 2001; Tang et al. 2024; Tsuchida et al. 2025). These bacteria live in a plaque matrix and thrive on the residue of sticky, sugary and starchy foods (Marsh 2006). Bacterial fermentation of carbohydrates creates acids which demineralise tooth enamel and begin the process of forming carious lesions, and a chronic, progressive decay of the tooth via destruction of the dentine and infiltration of the pulp chamber. Caries can form anywhere that plaque accumulates, but this occurs most commonly in interproximal spaces and the pits and fissures found on the crowns of the posterior teeth (Marsh 2006).

Not all foods are cariogenic. The predominant factor associated with dental caries is a diet rich in carbohydrates. Alongside the presence of dental plaque, caries develop from the action of oral bacteria that live in the plaque biofilm (Marsh 2006; Tsuchida et al. 2025). Increases in the rate of both dental caries and AMTL have been recorded in many populations in association with the transition to agriculture, reflecting a change to a more carbohydrate rich agricultural diet (Cohen and Armelagos 1984; Steckel and Rose 2002). On a scale of cariogenicity, from foods most likely to cause the formation of dental caries, to those that are least likely to cause caries, the most cariogenic substances are highly refined carbohydrates. This includes sweetened foods and drinks and also fermented beverages such as beer (Jayadevan and Vidyapeeth 2019).

In a pre-Columbian setting this could include *chicha*, fermented maize beer (Belmar et al. 2020; Falabella et al. 2008; Planella Ortíz 2019). Next on a scale of cariogenicity are unrefined carbohydrates, including cereals and starchy vegetables, such as maize. Cario-static foods are those which do not provide a food source for the oral bacteria that ferment and produce caries-forming acids. These include meats, seafood, nuts and some raw high-fibre plants with a low natural sugar content (Geddes 1994; Jayadevan et al. 2019; Yoshihara et al. 2009).

2.3.2 Periapical Cavities

Periapical cavities are voids formed around the apex of a tooth root and can be identified in archaeological remains through the presence of a fenestration in the alveolar process. They are often caused by dental abscesses, but can also result from periapical granulomata and periodontal cysts (Dias and Tayles 1997; Ogden 2008; Scheinfeld et al. 2012). In an archaeological setting, all such lesions are often recorded as dental abscesses, however, as it is difficult to distinguish between abscesses, granulomata and cysts in this context, they are referred to by the more generic term of periapical cavity in this paper.

The conditions that can lead to periapical cavities occur after exposure of the pulp chamber. Destruction of the tooth crown from carious lesions, advanced dental wear, or trauma, can all cause exposure of the pulp cavity, leaving it open to a high risk for infection (Burgos-Larraín et al. 2022; Jagadeesha et al. 2024). Bacteria infiltrating the exposed pulp chamber and travel to the base of the tooth root, causing destruction of the alveolar bone in the periapical region and potential formation of a dental abscess (Scheinfeld et al. 2012). As pressure accumulates from the build-up of pus at the root apex, a fistulae will form through the alveolar process to drain pus from the infection (Hillson 1986). Only after this drainage sinus has opened is it possible to identify the periapical cavity in archaeological remains without the use of radiography (Scheinfeld et al. 2012). For this reason, the prevalence of dental abscesses is likely underrepresented in bioarchaeological literature (Roberts and Manchester 2005).

Periapical granulomata and periodontal cysts are the result of low-grade infection of the pulp chamber. Granulation tissue formed from the infection accumulates around the affected tooth's root apex, creating a bony cavity with a smooth, sclerotic wall (Jagadeesha et al. 2024). Periodontal cysts are a sequelae to granulomata, forming when the granulation tissue is replaced by fluid, leaving a larger, circumscribed lesion in the alveolar bone (Dias and Tayles 1997; Jagadeesha et al. 2024). Both granulomata and cysts are typically asymptomatic. Abscesses, on the other hand, leave a rough-walled lesions if acute, with evidence of remodelling if chronic, and are the result of a more serious infection (Ortner 2003). Antemortem tooth loss is a common secondary effect of abscessing, and there is also a risk of hematogenous dissemination of the infection to other parts of the body, which can result in serious, life-threatening complications such as meningitis and osteomyelitis (Burgos-Larraín et al. 2022; Ortner 2003).

2.3.3 Antemortem Tooth Loss

Antemortem tooth loss (AMTL) occurs when so much of the supporting bone of the alveolar process has been lost that it can no longer sustain the tooth in position (Hillson, 2001). AMTL is a secondary condition that can result from infectious causes, such as dental caries and abscesses, other diseases with a dietary association, such as periodontal disease and scurvy, or degenerative causes, such as continued eruption of a tooth due severe attrition of the occlusal surface. AMTL can also be the result of traumatic injury, or intentional ablation for therapeutic, cultural or cosmetic reasons (Lukacs 2012; Roberts and Manchester 2005).

It is difficult to determine the cause of AMTL on an individual basis; however, a high prevalence of dental caries in populations with AMTL indicates a strong association between the two conditions (Hillson 2001; Larsen 1997). Among agriculturalists, AMTL is a usual sequela of penetrating dental caries, however, when present in hunter-gatherer populations the pathogenesis is generally severe occlusal wear (Lukacs 2017). In general, the prevalence of AMTL is seen to be higher among agriculturalists than hunter-gatherers (Larsen 1997).

The utility of caries and AMTL prevalence as an indicator of diet and subsistence has been demonstrated in numerous archaeological studies (Kelley et al. 1991). However, further investigation into the intricate interplay between these dental pathologies and dietary shifts, particularly the adoption of maize agriculture in pre-Columbian populations of the La Ligua and Aconcagua Valleys, is essential for a comprehensive understanding of the complex factors influencing oral health in diverse cultural and ecological contexts.

3. Materials and Methods

This study utilises data collected from multiple cemetery sites in the La Ligua and Aconcagua Valleys of Central Chile. In total, 177 individuals were examined, 16 from coastal sites and 161 from inland sites (Table 2). Only permanent dentition was included in the examination and analysis. For dental caries 3122 teeth were examined and for AMTL and the presence of periapical cavities 3286 alveoli were examined. Age and sex estimations for these individuals are available from previous bioarchaeological work in these valleys, as well as dietary stable isotope ($\delta^{13}C$ and $\delta^{15}N$) data for 161 of the same individuals (Swift in prep; Chapters 2 and 4).

The occurrences of dental caries, AMTL and periapical cavities are related to biological age, as the conditions develop progressively (Hillson 1996; 2001; Roberts and Manchester 2005). As such, when comparing rates of these dental pathologies across different groups, it is helpful to control for age where possible. Age estimations for the individuals were grouped into categories of 'child'(excluding deciduous dentition and including only erupted permanent dentition); 'young adult', 'adult', and 'mature adult'. These adult age categories correspond to various phases in the Lovejoy (1985) model that was used for estimating age-at-death from dental attrition (see methods sections in Chapters 1, 2 and 4): 'young adult' (wear stages B, C and D), 'adult' (E, F and G), 'mature adult' (H and I). The 'child' category was determined using Ubelaker's (1989) dental eruption charts for Native Americans, and corresponded to the eruption sequences in this resource up to and including '15years +- 3 years'.

Sites	*n*	Collection
Coastal Sites	*16*	
Concon and Camino Internacional	3	MHNV
Choncales de Longotomá	1	MLL
Dunos de Longotomá	1	MLL
El Membrillar	1	MHAQ
Los Coiles 136	7	MLL
Papudo	1	MLL
S-Bato 1	2	MHNV
Inland Sites	*161*	
Calle Arauco	1	MHAQ
Aspillaga I	1	MHAQ
Aspillaga II	4	MHAQ
Escuela de Placilla	14	MLL
Estadio de Quillota	78	MHAQ
Fundo Esmeralda	12	MHAQ
Los Andes	12	MLA
Las Chilcas	3	MHAQ
La Ligua	1	MLL
Maltería	2	MHAQ
Pueblo de los Indios	4	MHAQ
Pocochay	1	MLL
Quinquimo	1	MLL
Calle Ricardo, Santa Cruz	5	MHNV
Villa Alemana	1	MHNV
Valle Hermoso	21	MLL
Total	177	

Table 2: *Number of individuals from each site included in this study.*

**Collections: MHAQ = Museo Histórico-Arqueológico de Quillota, MHNV = Museo Historia Natural de Valparaíso, MLA = Museo Los Andes, MLL = Museo La Ligua.*

Dental caries, AMTL and periapical cavities were analysed by different dietary groups relating to the importance of maize in the diet. These dietary groups were determined by inland or coastal location and stable carbon isotope ($\delta^{13}C$) data which, in the absence of marine foods, provides a direct indication of the proportion of C_4 foods consumed (Table 3). The inland sites are defined as those which are located within or to the east of the coastal mountain range, and the coastal sites as those located on the coastal plains to the

west of coastal mountain range. Stable nitrogen ($\delta^{15}N$) isotope data mirror this geographical categorisation indicating marine-based (higher mean $\delta^{15}N$ values) and terrestrial-based diets (lower mean $\delta^{15}N$ values), for coastal and inland sites respectively (see Chapters 2 and 4 for further discussion).

		Dental Caries				**AMTL and Periapical Cavities**			
Setting and Diet	**Age**	**Total**	**F**	**M**	**I**	**Total**	**F**	**M**	**I**
Coast	*All*	*16*	*7*	*8*	*1*	*15*	*6*	*8*	*1*
Marine	All	9	3	6	0	8	2	6	0
	Adult (26-40)	1	1	0	0	1	1	0	0
	Mature (>40)	8	2	6	0	7	1	6	0
Marine C_4	All	7	4	2	1	7	4	2	1
	Child (<15)	1	0	0	1	1	0	0	1
	Young Adult (16-25)	4	3	1	0	4	3	1	0
	Mature (>40)	2	1	1	0	2	1	1	0
Inland	*All*	*161*	*55*	*63*	*43*	*140*	*51*	*61*	*28*
Predominantly C_3	All	21	5	9	7	17	5	9	3
	Child (<15)	2	0	0	2	0	0	0	0
	Adult (26-40)	4	1	3	0	4	1	3	0
	Mature (>40)	15	4	6	5	13	4	6	3
Mixed C_3-C_4	All	48	19	13	16	49	22	17	10
	Child (<15)	8	0	0	8	5	1	0	4
	Young Adult (16-25)	12	6	4	2	14	7	6	1
	Adult (26-40)	15	8	2	5	13	6	3	4
	Mature (>40)	13	5	7	1	17	8	8	1
Predominantly C_4	All	76	26	39	11	63	18	33	12
	Child (<15)	11	0	0	11	10	0	0	10
	Young Adult (16-25)	33	16	16	1	29	14	14	1
	Adult (26-40)	20	5	14	1	16	4	11	1
	Mature (>40)	12	3	9	0	8	0	8	0
No dietary data	All	16	5	2	9	11	6	2	3
	Child (<15)	2	0	0	2	0	0	0	0
	Young Adult (16-25)	5	2	0	3	4	3	0	1
	Adult (26-40)	4	3	1	0	4	3	1	0
	Mature (>40)	5	0	1	4	3	0	1	2
Total		**177**	**62**	**71**	**44**	**155**	**57**	**69**	**29**

Table 3: Number of individuals included in this study, presented by dietary groups, age groups, and sex.

Note: Indet. = indeterminate sex

The inland diets were divided into three categories representing the proportion of maize in the diet: 'predominantly C_3' (less than <25% maize), 'mixed C_3-C_4' (25-50% maize), and 'predominantly C_4' (greater than > 50% maize) (Table 4). Proportions of dietary C_4 were estimated using a simple linear extrapolation assuming dietary endpoints of -20.1‰ for a 100% C_3 diet and -4.7‰ for a 100% C_4 diet (based on $\delta^{13}C$ analysis of botanical samples, as described in Swift et al. (2017)), and then grouped by their $\delta^{13}C$ values.

Setting	**Dietary Group**	**$\delta^{13}C$ range**	**Estimated proportion of C_4 (maize)***
Inland	Predominantly C_3	-21.4‰ to -16.0‰	Less than <25%
	Mixed (C_3-C_4)	-15.9‰ to -12.0‰	Between 25-50%
	Predominantly C_4	-11.9‰ to -4.7‰	Greater than >50%
Coast	Marine	-18.2‰ to -13.9‰[+]	
	Marine-C_4	-12.3‰ to -10.1‰[+]	

Table 4: Broad dietary groups identified in the Aconcagua and La Ligua Valleys, based on coastal or inland setting, and stable carbon isotope data to estimate the dietary importance of maize, the predominant C_4 resource in the region.

**The estimated proportions of dietary C_4 for the inland groups are based on a simple linear extrapolation (as described in Swift et al. (2017)) utilising dietary endpoints determined from $d^{13}C$ analysis of Central Chilean botanical samples of -20.1‰ (for a 100% C_3 diet) and -4.7‰ for a (100% C_4 diet). This extrapolation can only be applied to the inland sites where $d^{13}C$ values are not conflated with elevated $d^{13}C$ from marine proteins.*

[+]The 'Marine' and 'Marine-C_4' diets were determined based on dietary isotopes (Chapters 2 and 4) and the archaeological background of the coastal sites, which each pertain to one temporal phase only: The Late Intermediate Period site of Los Coiles 136 with evidence of maize in the diet ('Marine-C_4' diet), and the Early Ceramic Period sites Concon and Camino Internacional, El Membrillar II, Longotoma, Papudo and S-Bato 1 without evidence of maize in the diet (Chapters 2 and 4).

3.1 DENTAL CARIES

Permanent teeth were examined macroscopically for the presence of dental caries. Carious lesions were recorded for each tooth surface with evidence of a necrotic cavity, as described by Hillson (2001). Caries rates were calculated as the number of teeth with caries over the total number of teeth observed. However, this conventional caries rate does not reliably reflect a true caries prevalence, underestimating the real caries rate as it fails to account for the effect of AMTL (a common sequela of caries) or the differences between anterior (incisors and canines) and posterior teeth (premolars and molars) in cariogenic resistance and susceptibility to post-mortem tooth loss (PMTL) (Duyar and Erdal 2003; Hillson 2001). Therefore, a Caries Correction Factor (CCF) was first applied, followed by a Proportional Correction Factor (PCF) in order to provide a more reliable estimate of the true caries frequencies. These correction factors were applied to account for the likely underestimation of caries prevalence due to tooth loss. While not universally applied in recent literature it remains a valid approach when preservation is variable and AMTL is substantial, and is strongly advocated by leading authorities in dental anthropology such as Hillson (2001). Both uncorrected and corrected frequencies are presented in all caries results tables.

The CCF was applied following Lukacs (1995), which estimates the proportion of AMTL due to caries by calculating the proportion of pulp exposure per individual due to caries compared to the proportion of pulp exposure due to attrition, and applied this to the estimated caries rate. This was followed by the application of a PCF, to account for differential PMTL and caries susceptibility between anterior and posterior teeth. The PCF was applied by multiplying the CCF for anterior and posterior teeth separately by 0.378 and 0.625 respectively, as per Duyar and Erdal (2003). These correction factors of 0.378 and 0.625 equate to the proportions of anterior teeth in the complete adult dentition (12 out of 32 teeth, or 3/8 per dental quadrant) and posterior teeth in complete adult dentition (20 out of 32, or 5/8 per quadrant). The anterior and posterior PCFs were then summed together to provide proportionally corrected estimated caries rates.

3.2 PERIAPICAL CAVITIES

Periapical cavities were identified as lesions in the alveolar bone around tooth root apices, visible by fistulae which had perforated the overlying bone. Periapical cavities were recorded per observable alveolus.

3.3 AMTL

An assessment of AMTL was recorded for every observable tooth socket. AMTL was distinguished from post-mortem tooth loss (PMTL) by the presence of bony remodelling of the affected alveolus.

3.4 STATISTICS

The normality of distributions was assessed using Shapiro-Wilk tests. Comparisons for each of the dental conditions (caries, AMTL, and periapical cavities) across sub-groups of setting (coastal and inland), age groups (child, young adult, adult, and mature) and dietary groups (C_3, mixed C_3–C_4, and C_4 for inland data, and marine and marine-C_4 for coastal data) were carried out with Student's t-tests (2 groups) or ANOVA (>2 groups) for normally distributed data, and Mann-Whitney U tests (2 groups) or Kruskal-Wallis tests (>2 groups) for non-normally distributed data. Post-hoc Bonferroni corrections were applied after all ANOVA and Kruskal-Wallis tests.

All statistical analyses and data visualisations were carried out and created using R version 3.5.0 (RCoreTeam 2018) with RStudio 1.3.1056 (RStudioTeam 2020).

4. Results

4.1 DENTAL CARIES

The frequencies of dental caries for several of the dietary subgroups are not normally distributed (Marine: no dental caries, Marine-C_4: p=0.01, C_3: p< 0.001, C_3-C_4: p<0.001, C_4: p<0.001). Therefore, non-parametric comparisons of means tests were employed for the analysis of dental caries frequencies between groups.

Dental caries were observed in 10.2% of all teeth when a PCF was applied, and 47.5% of all individuals (Table 5). The frequency of teeth with dental caries was higher for the inland sites (10.9%) compared to the coastal sites (3.2%); however, this difference just fails to be statistically significant at $p<0.05$ (Z=-1.920, U=943.5, p=0.056).

Dental Pathology and Setting	Condition Present per Tooth	Teeth Observed	Frequency (%) *	Condition Present in Individual	Individuals Examined	Frequency (%)
Caries	269	3122	(8.6) 10.2	84	177	47.5
Coast	8	321	(2.5) 3.2	4	16	25.0
Inland	261	2801	(9.3) 10.9	80	161	49.7

Table 5: *Summary of dental caries presented as frequencies of affected teeth, and as frequencies of affected individuals*

** Frequencies (%) are reported using a Proportional Correction Factor (PCF) % as per Duyar and Erdal (2003). The raw frequency is presented in brackets before the corrected frequency.*

There is a significant difference in the frequency of teeth with caries across the different age groups, with the lowest occurrence in children (2.2%), followed by mature adults (8.3%), young adults (13.1%), and adults (13.2%) ($\chi^2(3)$ =8.87, p=0.031). Post-hoc pairwise comparisons demonstrated that it is the children who are significantly different, with lower rates of caries than the older age groups. As would be expected, caries occurred at a significantly higher rate in the posterior teeth (14.5%), as opposed to the anterior teeth (4.7%) (Z=- 5.872, U= 11129, p<0.001).

The somewhat lower frequency of caries in mature adults compared to younger adults is likely an artefact of age-related AMTL. Because carious teeth are often lost over time, and as an individual ages, this results in an under-representation of caries in the dentitions of older age groups. Thus, caries and AMTL should not be treated as entirely independent pathologies (Duyar and Erdal 2003). Instead, they represent related outcomes on a continuum of oral health decline. This is supported by the relatively higher rates of AMTL recorded among adults and mature adults in this study (see Section 4.2).

4.1.1 Dietary groups

Coast

No caries were observed among the marine diet group of the coastal sample, whereas 7.2% of teeth from the marine-C_4 diet group were affected by dental caries, a statistically significant difference (Z=2.434, U=13.5, p=0.015) (Table 6). There are insufficient samples to examine the coastal dietary groups by smaller sub-categories, such as age groups and sex.

	Marine			Marine-C_4				
Dental Pathology	Condition Present	Teeth Observed	Freq. (%)*	Condition Present	Teeth Observed	Freq. (%)*	Test Score	*p* value
Caries	0	173	(0.0) 0.0	8	148	(5.4) 7.2	2.434	**0.015**

Table 6: *Summary and statistical comparison of dental pathologies presented as frequencies of affected teeth for coastal dietary groups.*

** Frequencies (%) are reported using a Proportional Correction Factor (PCF) % as per Duyar and Erdal (2003). The raw frequency is presented in brackets before the corrected frequency.*

Statistically significant differences between the dietary groups at p<0.05 are presented in bold.

Inland

There is a significant difference in the caries frequency between the different inland dietary groups ($\chi^2(2) = 7.62$, $p = 0.022$), with post-hoc tests demonstrating that dental caries occurred significantly more frequently in the C_4 dietary group than in the C_3 group (Table 7). This same pattern of significantly increased dental caries after the introduction of C_4 foods to the diet is also observed when comparing caries frequency in posterior teeth ($\chi^2(2)=7.79$, $p=0.020$), but not for anterior teeth ($\chi^2(2)=1.14$, $p=0.566$).

	C_3			Mixed			C_4				
Dental Pathology	Condition Present	Teeth Observed	Freq. (%)*	Condition Present	Teeth Observed	Freq. (%)*	Condition Present	Teeth Observed	Freq. (%)*	Test Score	*p* value
Caries	20	205	(9.8) 8.3	77	795	(9.7) 9.4	140	1531	(9.1) 13.0	7.62	**0.022**
Child (<15)	0	27	(0.0) 0.0	6	193	(3.1) 2.9	1	220	(0.5) 2.3	1.27	0.530
YA (16-25)	0	0		13	245	(5.3) 6.3	77	725	(10.6) 15.8	0.88	0.381
Adult (26-40)	0	16	(0.0) 0.0	34	189	(18.0) 14.6	41	308	(13.3) 16.0	3.96	0.138
MA (>40)	20	162	(12.3) 11.6	24	168	(14.3) 10.3	21	278	(7.6) 10.1	2.72	0.256

Table 7: Summary and statistical comparisons of dental caries presented as frequencies of affected teeth for inland dietary groups across different age groups. YA = Young Adult, MA = Mature Adult.

** Frequencies (%) are reported using a Proportional Correction Factor (PCF) % as per Duyar and Erdal (2003). The raw frequency is presented in brackets before the corrected frequency.*

Statistically significant differences between the dietary groups at p<0.05 are presented in bold

Similarly, the likelihood of an individual having dental caries at all is also strongly correlated with higher $\delta^{13}C$ bone collagen values, and therefore the dietary inclusion of C_4 resources (*Z*=-2.327, *U*=1998, *p*=0.020) (Figure 2). No significant relationship was found between $\delta^{15}N$ and the occurrence of dental caries (*Z*=-1.835, *U*=2121, *p*=0.067).

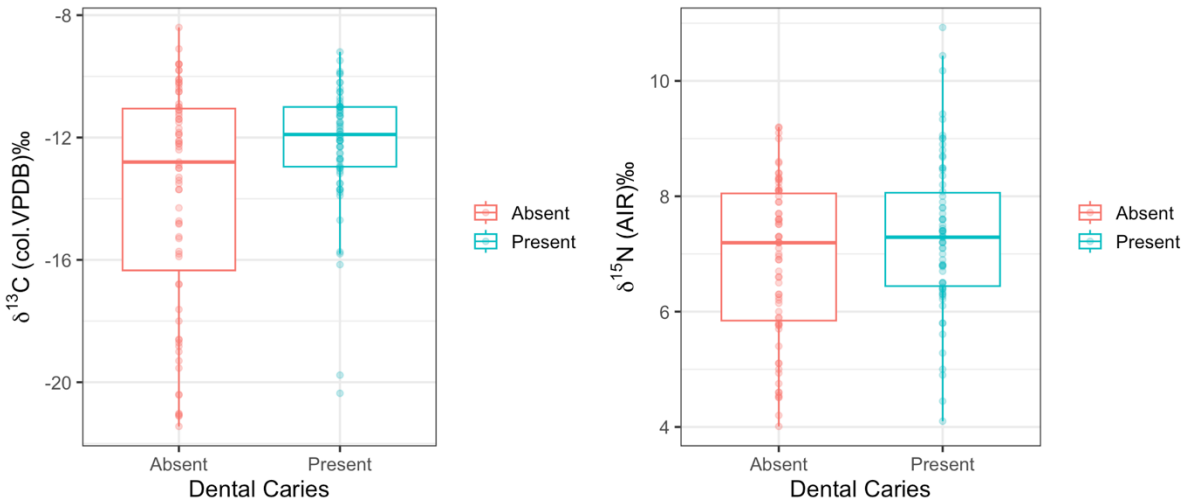


Figure 2: Box plots of $d^{13}C$ (left) and $d^{15}N$ (right) distributions for individuals with dental caries ("present") compared to individuals without dental caries ("absent").

When the frequency of dental caries is examined by location on the tooth (occlusal, crown, cemento-enamel junction, interstitial, root, or gross gross caries), a significant difference is observed across the three inland dietary groups for the dental caries located on occlusal surfaces ($\chi^2(2) = 6.74$, $p = 0.034$), with the mixed C_3-C_4 dietary group having significantly higher occlusal caries than the C_3 group. This pattern was not found for other caries locations: crown, cemento-enamel junction, interstitial, root, or gross gross caries.

Age groups by diet

When examined by age, all categories, except for the mature adults group, reflect the same pattern of an increase in the frequency of teeth affected by dental caries with the shift from a C_3-based diet to a diet with a mixed input of C_3 and C_4 foods. Frequencies per tooth for the mature adults remain relatively consistent across dietary groups, however, the frequency of mature adult individuals affected by dental caries follow the pattern of increasing with the shift from a C_3-based diet to a mixed C_3-C_4 diet. Even though these patterns of increasing dental caries alongside increasing dietary C_4 are relatively consistent, they did not reach statistical significant for any of the age groups (Child: $\chi^2(2) = 1.27$, $p = 0.530$; Young Adult: Z=0.8757, U=231.5, p= 0.381; Adult: $\chi^2(2) = 3.96$, $p = 0.138$; Mature: $\chi^2(2) = 2.72$, $p = 0.256$).

Sex differences in caries across dietary groups controlled for age

Females consistently have more dental caries than males. Across each dietary group and all age groups, this pattern remains the same. However, only among the C_4 dietary group is this difference statistically significant (Z= 3.282, U=693, p<0.001).

4.2 AMTL

Non-parametric comparisons of means tests were employed for the analysis of AMTL frequencies between groups as the frequencies of AMTL for most of the dietary subgroups were not normally distributed (Marine: p=0.008, Marine-C_4: p=0.067, C_3: p< 0.001, C_3-C_4: p<0.001, C_4: p<0.001).

AMTL affected 10.2% of all alveoli and was present in 42.6% of all individuals (Table 8). The frequency of AMTL is higher at inland sites (10.9%) than coastal sites (6.2%), but the difference is not large enough to be statistically significant (Z=-0.6271, U=951.5, p=0.5306). Posterior teeth (12.6%) were affected by AMTL at a significantly higher rate than anterior (6.0%) (Z=-4.741, U=9048, p<0.001).

Dental Pathology and Setting	Condition Present in Alveoli	Alveoli Observed	Frequency (%)	Condition Present in Individual	Individuals Examined	Frequency (%)
AMTL	336	3286	10.2	66	155	42.6
Coast	24	389	6.2	7	15	46.7
Inland	312	2897	10.9	59	139	42.4

Table 8: *Summary of AMTL presented as frequencies of affected alveoli, and as frequencies of affected individuals*

Children were unaffected by AMTL, but the condition was observed in all other age categories (young adult 9.2%, adult 16.5%, and mature 11.6%). The difference in frequencies across the age categories is statistically significant ($\chi^2(3)$=16.7, p<0.001) with post-hoc analysis demonstrating that the child age category is significantly different from the other age categories.

4.2.1 Dietary Groups

Coast

Even though there is an increase in the frequency of AMTL observed per alveolus from the marine diet (3.9%) to the marine-C4 diet (8.2%), the difference is not large enough to be statistically significant (Z=-0.566, U=24.5, p=0.572) (Table 9).

	Marine			Marine-C4				
Dental Pathology	Condition Present	Teeth / Alveoli Observed	Freq. (%)*	Condition Present	Teeth / Alveoli Observed	Freq. (%)	Test Score	*p* value
AMTL	7	197	4.6	17	208	8.0	-0.760	0.447

Table 9: *Summary and statistical comparison of AMTL presented as frequencies of affected alveoli for coastal dietary groups.*

Statistically significant differences between the dietary groups at p<0.05 are presented in bold.

Inland

The inland dietary groups followed a similar pattern to dental caries, with an increase in the frequency of ATML from the predominantly C_3-diet to the mixed C_3- C_4 diet (Table 10). Unlike the pattern of dental caries, there is a slight decrease in the frequency of AMTL from the mixed diet to the more intensively C_4-based diet. Despite the patterns of AMTL frequencies reflecting those observed for dental caries, the differences observed for AMTL are not statistically significant across the dietary groups ($\chi^2(2) = 5.88$, $p = 0.052$), possibly due to the overall reduced sample size of AMTL compared to dental caries. The differences observed across the dietary groups are also not significant when broken down into age groups (Young Adult: $Z=0.295$, $U=183$, $p=0.768$; Adult: $\chi^2(2)=4.20$, $p=0.122$; Mature Adult: $\chi^2(2)=2.74$, $p=0.255$). Likewise, there was not a significant correlation between $\delta^{13}C$ or $\delta^{15}N$ values and whether individuals were affected by AMTL or not ($\delta^{13}C$: $Z=-1.375$, $U=2126.5$, $p=0.169$; $\delta^{15}N$: $Z= 0.200$, $U=2509$, $p=0.841$).

	C_3			Mixed			C_4				
Dental Pathology	Condition Present	Alveoli Observed	Freq. (%)	Condition Present	Alveoli Observed	Freq. (%)	Condition Present	Alveoli Observed	Freq. (%)	Test Score	*p* value
AMTL	14	230	6.1	141	981	14.4	128	1412	9.1	5.88	0.052
Child (<15)	0	0		0	139	0.0	0	224	0.0		
YA (16-25)	0	0		24	316	7.6	54	693	7.8	0.30	0.768
Adult (26-40)	1	36	2.8	41	199	20.6	65	301	21.6	4.20	0.122
MA (>40)	13	194	6.7	76	327	23.2	9	194	4.6	5.99	0.050

Table 10: Summary and statistical comparisons of dental caries presented as frequencies of affected teeth for inland dietary groups across different age groups.

YA = Young Adult, MA = Mature Adult

Statistically significant differences between the dietary groups at p<0.05 are presented in bold

Sex differences in AMTL across dietary groups

Females experienced more AMTL than males (17.2% of alveoli affected for females vs 6.6% for males) a pattern which remains consistent across each dietary and age group. However, it is only among the C_4 dietary group that there is a statistical significance between the AMTL experienced by the sexes (Z=2.213, U=437, p=0.027) with a frequency of 20.5% of alveoli affected by AMTL for female C_4 consumers and 4.7% of alveoli affected in male C_4 consumers.

4.3 PERIAPICAL CAVITIES

Shapiro-Wilk tests demonstrated a significant departure from normality for the frequencies of periapical cavities in several of the dietary subgroups (Marine: p=0.008, Marine-C_4: p=0.011, C_3: p< 0.001, C_3-C_4: p<0.001, C_4: p<0.001).

Periapical cavities were present in 1.3% of all alveoli (14.8% of all individuals) (Table 11). The frequency of affected alveoli was significantly higher at coastal sites (2.6%) than inland sites (1.2%) (Z=2.726, U=1334, p=0.006). However, the sample size for the coastal group is small (n = 389 alveoli, only 15 individuals), and this result should therefore be interpreted with caution. No periapical lesions were observed in children, but were present in all other age categories (young adult 1.3%, adult 2.4%, and mature 1.3%). There was no significant difference in the frequency at which anterior and posterior teeth were affected by periapical cavities (Z=-1.5773, U=10620.5, p=0.115).

Dental Pathology and Setting	Condition Present in Alveoli	Alveoli Observed	Frequency (%)	Condition Present in Individual	Individuals Examined	Frequency (%)
PC	44	3286	1.3	23	155	14.8
Coast	10	389	2.6	5	15	33.3
Inland	34	2897	1.2	18	140	12.9

Table 11: *Summary of PC (Periapical Cavities) presented as frequencies of affected alveoli, and as frequencies of affected individuals*

4.3.1 Dietary Groups

Coast vs Inland

Among the coastal groups, there was no significant difference in the frequency of periapical cavities between the marine (2.8%) and marine-C_4 (2.4%) dietary groups (Z=0.065, U=29, p=0.948) (Table 12). Among the inland dietary groups, the C_4 consumers have a higher rate of periapical cavities (1.7%) than the C_3 (0.4%) and mixed (0.6%) dietary groups, however, the difference is not large enough to be statistically significant ($\chi^2(2) = 3.81$, p=0.149) (Table 13). There was also no significant correlation between and $\delta^{13}C$ and the likelihood an individual is affected by periapical cavities (Z=-1.485, U=780, p=0.138), or $\delta^{15}N$ and periapical cavities (Z=-1.013, U=849.5, p=0.311).

	Marine			Marine-C_4				
Dental Pathology	Condition Present	Alveoli Observed	Freq. (%)	Condition Present	Alveoli Observed	Freq. (%)	Test Score	*p* value
PC	5	181	2.8	5	208	2.4	0.065	0.948

Table 12: *Summary and statistical comparison of PC (periapical cavities) presented as frequencies of affected alveoli for coastal dietary groups.*

Statistically significant differences between the dietary groups at p<0.05 are presented in bold.

Inland age groups by diet

A trend of increasing frequency of periapical cavities with the increasing inclusion of C_4 in the diet was observed for adults (except children for whom no periapical cavities were recorded). However, these patterns were not statistically significant (Young Adult: Z=0.758, U=194, p=0.449; Adult: $\chi^2(2)$=2.72, p=0.257;

Mature Adult: $\chi^2(2)=1.79$, $p=0.409$). The biggest increases in the frequencies of periapical cavities occurred with the shift from the mixed C_3-C_4 diet to the C_4 diet. This is slightly different to dental caries and AMTL which both experienced their biggest shifts between the shift from a predominantly C_3 diet to a mixed C_3-C_4 diet. Either way, all of the dental pathologies recorded in this study demonstrated a trend towards increasing prevalence from the frequencies observed in the C_3 diet to one of the diets involving a greater proportion of maize, be that the mixed C_3-C_4 diet or the C_4 diet.

	C_3			Mixed			C_4				
Dental Pathology	Condition Present	Alveoli Observed	Freq. (%)	Condition Present	Alveoli Observed	Freq. (%)	Condition Present	Alveoli Observed	Freq. (%)	Test Score	*p* value
PC	1	230	0.4	6	981	0.6	25	1444	1.7	3.81	0.149
Child (<15)	0	0		0	139	0.0	0	256	0.0		
YA (16-25)	0	0		1	316	0.4	12	693	1.7	0.76	0.449
Adult (26-40)	0	36	0.0	1	176	0.5	12	301	4.0	2.72	0.257
MA (>40)	1	194	0.5	4	350	1.1	1	194	0.5	1.79	0.409

Table 13: *Summary and statistical comparisons of periapical cavities (PC) presented as frequencies of affected teeth for inland dietary groups across different age groups.*

YA = Young Adult, MA = Mature Adult

Statistically significant differences between the dietary groups at p<0.05 are presented in bold

Sex differences in periapical cavities across dietary groups

No periapical cavities were recorded for either sex in the C_3 diet group. The only individual affected by periapical cavities in this group was a mature adult from the Inland Valley site of Villa Renacer 2, Rinconada, whose remains were inadequately preserved to assess sex. In both the mixed and C_4 dietary groups, males had very slightly more alveoli affected by periapical cavities than females, but these differences were not large enough to be statistically significant (mixed: males=0.8%, females=0.6%, $Z=0.309$, $U=123.5$, $p=0.757$; C_4: males=2.0% females=1.9%, $Z=-0.077$, $U=392$, $p=0.939$)

5. Discussion

5.1 DENTAL PATHOLOGIES AND THE INTENSIFICATION OF MAIZE AGRICULTURE

Dental pathologies have long been held as an important indicator of changes in subsistence strategies and a marker of the transition from foraging to farming. This is a trend that has been observed globally with only a few exceptions (Steckel and Rose 2002). The increase in dental pathologies alongside this important transition in human history is often attributed to the higher carbohydrate content of the staple crops of a farming diet. Given the known cariogenicity of maize as a staple food, it is unsurprising that maize agriculture has likewise been observed to follow the same pattern of worsening dental health alongside the increased exploitation of this resource.

The Aconcagua Valley, in particular, was a pre-Columbian epicentre for maize, with the transition to maize agriculture in the Aconcagua and Ligua Valleys occurring around cal AD 450-600, followed by an intensification in farming and coincident dominance of maize as the primary food staple (Chapter 4). The new data from the La Ligua and Aconcagua Valleys presented here reflect the impact of this transition. Caries, AMTL and periapical cavities all increase with the introduction of C_4 resources to the diet (Figure 3). The raw frequencies observed in the Aconcagua and La Ligua Valleys are somewhat lower than those recorded in other concurrent populations from the hyper-arid and semi-arid north of Chile (Andrade 2012; Kelley et al. 1991). However, the pattern of increasing rates of dental caries and AMTL after the introduction of maize agriculture nonetheless mirrors that which has been observed in other South Central Andean populations.

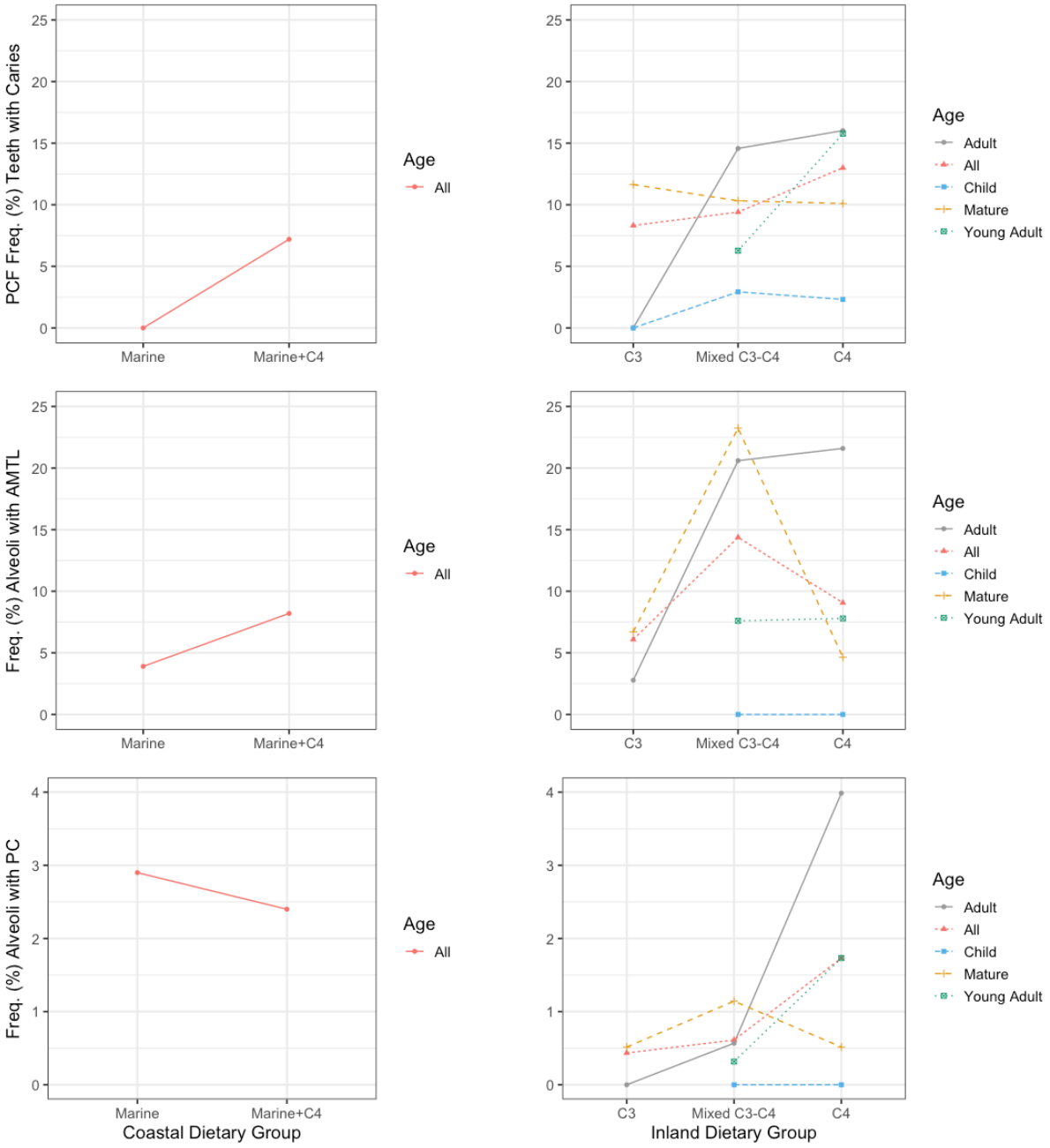


Figure 3: Frequencies of dental caries, AMTL, and periapical cavities observed for coastal (left column) and inland (right column) dietary groups.

Top row: Frequency (%) of teeth with dental caries, with Proportional Correction Factor (PCF) applied, for coastal and inland dietary groups.

Middle row: Frequency (%) of alveoli with ante-mortem tooth loss (AMTL) for coastal and inland dietary groups.

Bottom row: Frequency (%) of alveoli periapical cavities (PC) for coastal (left column) and inland dietary groups.

Among the inland groups from Central Chile, all three of the dental pathologies follow the same pattern of increasing frequency after maize has been introduced to the diet, as determined by the stable isotope data from human bone collagen with increased $\delta^{13}C$ values indicating either mixed C_3-C_4 or C_4 diets. Overall, there is a pattern of increasing caries prevalence and increasing periapical cavities prevalence from the C_3 to the mixed to the C_4 diet. AMTL, on the other hand, demonstrates a peak in the mixed diet before a slight drop to the C_4 diet. Among the coastal groups the same trend is apparent for caries and AMTL increasing in frequency with the change from a marine to a mixed marine-C_4 diet. However, it is only dental caries for which the data demonstrate a statistically significant increase at both coastal and inland settings.

Dental caries, AMTL and PC were all observed more frequently in the older (adult and mature adult) age categories than the younger (child and young adult) groups. This trend is as expected given that these lesions are progressive in nature, where cumulative exposure to dietary and environmental factors leads to higher pathology rates with age.

When considering the frequencies of the dental pathologies for each age group across the inland dietary categories the adults and children experienced an increase in dental caries increased from the C_3 diet to the mixed C_3-C_4 diet. This trend continued with further increases in caries frequencies from the mixed C_3-C_4 diet to the C_4 diet for adults and young adults. The relatively consistent caries frequencies observed in mature adults across dietary groups may indicate that, by this stage, their dental health had already reached a threshold where further changes in diet had minimal additional impact, or they had simply lost many of the susceptible teeth earlier in life.

For all age groups, the highest frequencies of AMTL were experienced with the mixed C_3-C_4 diet, before a decrease in frequencies in the C_4 dietary group, but nonetheless remaining higher than the frequencies of the predominantly C_3 diet. The prevalences of periapical cavities are slightly different in that they continue to rise, across all the age categories, from the C_3 diet, to the mixed to a peak with the C_4 diet. It is evident from this newly presented data for Central Chile that an increase in the dental pathologies examined was experienced after the shift from a C_3-based diet to one which includes the more regular consumption of maize, being either the mixed C_3-C_4 or the C_4 dietary group. This highlights the broader impact of agricultural intensification on oral health, consistent with global patterns observed in populations transitioning agriculture.

5.2 DENTAL HEALTH AND A COASTAL VS AN INLAND DIET

The frequency of dental caries and AMTL is higher among inland individuals than coastal individuals, but the pattern is reversed for periapical cavities which are more common among the coastal individuals. Similar trends have been observed on the California coast, with an increase in periapical cavities coincident with a pre-Hispanic shift from a carbohydrate rich terrestrial diet based on plant resources to a more protein rich intensive marine diet (Walker and Erlandson 1986). It is likely that the lower-carbohydrate and higher-protein intake of a diet based on marine foods also plays a role in the decreased caries and AMTL rates observed for the coastal sites in Central Chile compared to the inland individuals with a terrestrially based diet.

Coastal diets are known to be associated with more advanced dental wear, and indeed lower rates of dental caries and AMTL (Littleton and Frohlich 1993). Marine diets can include coarse particles and grit resulting in greater wear on the teeth. Advanced dental attrition is a major factor that contributes to the development of dental abscesses and periapical cavities (Langsjoen 1988). Severe wear can expose the pulp cavity of the tooth to infectious pathogens and subsequent formation of periapical cavities (Langsjoen 1988; Ortner 2003), hence the potential for periapical cavities to occur more frequently among coastal populations.

Increased dental wear also has a counterbalancing effect of reducing dental caries (Langsjoen 1988; Ortner 2003). Occlusal surfaces can simply be ground away before dental caries have the chance to develop. Furthermore, when occlusal surfaces are worn flat, there are fewer or no pits and fissures for food particles to become trapped and create a microenvironment within which carious lesions begin to form. Another factor that may be associated with decreased frequencies of dental caries in coastal populations is the increased availability of fluoride in the diet. Fluoride is found in higher concentrations in marine foods (Herta et al. 1970; Malde et al. 1997; Siebert and Trautner 1985), and it has been inferred that this may be another factor that impedes the development of dental caries in coastal populations (Keenleyside 2008).

5.3SEX DIFFERENCES IN THE DENTAL HEALTH EXPERIENCE

Bioarchaeologists have often argued that sex-based differences in the rate of dental caries are the result of sex-based dietary differences (Larsen, 1997; Hillson, 2008). However, the long-held paradigm of dental caries being a direct reflection of diet has recently been challenged as somewhat simplistic, and failing to consider the more complex multifactorial pathogenesis of dental pathologies (Marklein et al. 2019). It is generally observed that females experience higher rates of dental caries compared to males, a pattern which holds true across various cultures, subsistence strategies and chronological periods (Bertilsson et al. 2021; Bonsall 2014; Carvalho et al. 2019; Lopez et al. 2012; Lukacs and Thompson 2008; Namal et al. 2008; Walter et al. 2016; Willis and Oxenham 2013), notwithstanding there are some exceptions (Esclassan et al. 2009; Šlaus 2000; Trombley et al. 2019). This is a trend which is also observed in modern clinical data (Carlos and Gittelsohn 1965; Ferraro and Vieira 2010; Galvão-Moreira et al. 2018; Shaffer et al. 2015).

Sex-related differences in the prevalence of dental caries can be related to several factors, including sex-based differences in oral biology, hormonal differences, and extrinsic factors that influence hormonal variations such as increased fertility and birth rates from changing population dynamics. For example, saliva has a protective effect for oral health through pH buffering, antimicrobial action and simply by assisting in

clearing food from around the teeth (Burakoff 2003; Laine 2002; Silk et al. 2008; Steinberg 2000). Saliva quantity, flow rate and salivary gland size are all typically lower or smaller in females, thus females experience reduced protective effects from saliva (Percival et al. 1994; Sreebny 2000).

Furthermore, oestrogen hormone levels are positively correlated with the development of dental caries (Delman 1955; Laine 2002; Liu and Lin 1973). Hormonal variations experienced by women impact upon saliva quantity and biochemistry, with increased oestrogen resulting in a drier and more acidic oral environment. Fluctuations in oestrogen can reduce saliva flow and lead to a more acidic oral environment (Yang et al. 2024). Hormonal changes also affect the metabolism of calcium, and levels of salivary calcium and phosphate, which can make tooth enamel more vulnerable to demineralisation and caries formation (Laine 2002; Shetty et al. 2023).Other factors experienced with hormone variations and pregnancy, such a food cravings, aversions and morning sickness can also play a role in the development of dental lesions (Flaxman and Sherman 2000; Vallianatos 2007).

A reproductive ecology model indicates that reproductive-age women in populations with higher fertility and birth rates will experience an increased prevalence of dental pathologies, particularly dental caries (Lukacs 2012; Lukacs and Largaespada 2006). The transition to agriculture in pre-history not only resulted in dietary changes, but had farther reaching impacts, referred to as the Neolithic Demographic Transition in the Old World, including changes in settlement patterns, increased sedentism, significant population increases and increased fertility and mortality rates (Bocquet-Appel 2002; Bocquet-Appel and Naji 2006). Indeed Lukacs (2008) posits that increased rates of dental caries in females compared to males should be expected in agricultural populations due to a concomitant increase in fertility rates and the biological impact this has on women in pre-disposing them to poorer oral health.

For the Aconcagua and La Ligua Valleys, the prevalence of caries and AMTL is indeed higher among females than males across all dietary categories. In the case of dental caries, this difference is even more pronounced after the introduction and increase of C_4 foods in the diet (Figure 4). While diet is undeniably an important factor in the pathogenesis of dental caries, the differential increase in this condition in females compared to males, a gap that widens further after the introduction of agriculture, likely points to other factors increasing female susceptibility, such as the compounding factors of sex-based susceptibility to dental caries alongside increased fertility and higher birth rates that typically accompany increased sedentism and the intensification of agriculture.

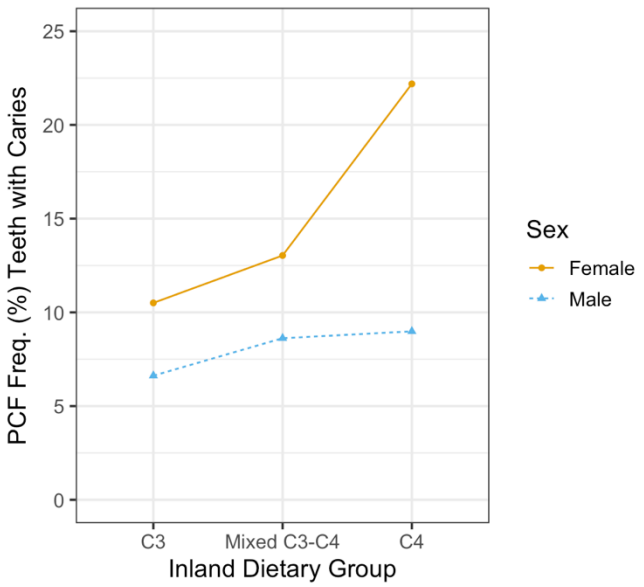


Figure 4: Frequency (%) of teeth with dental caries, with PCF applied (left), presented for males and females across inland dietary groups.

	Predominantly C_3 Diet				Mixed C_3-C_4 Diet				Predominantly C_4 Diet			
	Mean $\delta^{13}C$ (‰)	SD	Mean $\delta^{15}N$ (‰)	SD	Mean $\delta^{13}C$ (‰)	SD	Mean $\delta^{15}N$ (‰)	SD	Mean $\delta^{13}C$ (‰)	SD	Mean $\delta^{15}N$ (‰)	SD
Female	-18.51	1.8	5.72	5.9	-13.59	1.1	6.73	1.5	-11.35	0.6	7.46	0.8
Male	-19.9	1.4	5.69	5.6	-13.68	1.2	6.71	1.1	-10.66	0.9	7.99	1.0
Test score (*U*)	34		23		132.5		136		283		352.5	
p value	0.1469		1		0.9412		0.8417		**0.0027**		**0.0391**	

Table 14: *Mean stable carbon ($d^{13}C$) and stable nitrogen ($d^{15}N$) isotope values for females and males presented across inland dietary groups. Significant p-values presented in bold.*

Dietary stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) from bone collagen of the same individuals demonstrates that there is no significant dietary difference, based on the isotopic data, between males and females within the C_3 dietary group or the mixed C_3-C_4 group. However, a significant difference in $\delta^{13}C$ between males and females is apparent for the C_4 dietary groups (p=0.002), indicating a greater proportion of C_4 resources in the male diet compared to the female diet (Table 14). Using a model that assumes diet was the sole contributing factor to the formation of dental caries, the expectation would be that males should experience these conditions at a greater frequency than females in instances where males have preferential access to maize in their diets, given the known cariogenicity of maize. However, even though the isotopic evidence demonstrates that males did have increased access to maize in the mixed and C_4 dietary groups, the pattern of dental caries is the opposite, with females not just experiencing a higher prevalence across all dietary groups, but becoming increasingly more afflicted by caries than males alongside the intensification of maize agriculture, reaching prevalence rates 2.5 times higher than males for caries in the C_4 dietary group. This division in caries frequencies points to the impact of intrinsic, sex-based, factors influencing susceptibility to dental caries as well as other factors that are indirectly associated with the intensification of agriculture, such as increased fertility and birth rates that co-occur alongside a transition from hunting and gathering to the adoption and intensification of agriculture, and not just the increase of cariogenic foods (maize) in the diet alone.

6. Conclusion

The study of dental pathologies can provide valuable insights into the health and dietary practices of past populations. This research contributes to the broader understanding of how subsistence strategies affect health outcomes, and that such changes can be represented by the prevalence of dental lesions. Despite a rich archaeological record, Pre-Columbian Central Chile, including the Aconcagua and La Ligua Valleys, is underrepresented in palaeopathological literature. This study presents new data for three key pathological dental lesions, dental caries, AMTL, and periapical cavities in pre-Columbian populations of the Aconcagua and La Ligua Valleys from the Early Ceramic Period, through the Late Intermediate and into the Late Period (ca. 300 BC – AD 1536). Analyses of these indicators of oral health, alongside recent stable carbon and nitrogen isotope data, demonstrated an increase in dental caries, AMTL and periapical cavities coinciding with the introduction of maize as a dietary staple. However, only dental caries sees a large enough increase to reach statistical significance alongside this dietary transition.

The new data from the Aconcagua and La Ligua Valleys presented here highlight the impact of the transition to maize as dietary staple. The patterns of increased dental pathologies were observed for inland and coastal populations, as well as across different age categories. The availability of dietary isotope data from the same Central Chilean individuals indicates that the shift to more regular consumption of maize is a key factor associated with a higher frequency of dental pathologies. The results from Central Chile reflect similar global patterns of declining oral health alongside the transition to agriculture (e.g. Cohen and Armelagos 1984; Steckel and Rose 2002; Turner 1979), as well as patterns observed among other South Central Andean populations to the north (Alfonso et al. 2007; Kelley et al. 1991; Watson et al. 2010).

The widely observed pattern of increasing dental pathologies accompanying the transition to agriculture has generally been attributed to the increase of fermentable carbohydrates in the diet. While the food people consume has an undeniable role in oral health, considering only diet in the pathogenesis of these dental

conditions may be oversimplistic and overlooks some of the other factors known to be associated with oral health. For example, food preparation methods, oral hygiene practices, and numerous biochemical and physiological factors related to differences between sexes (Lukacs and Largaespada 2006). The availability of stable isotope data for the Central Chilean sample provided an opportunity to control for diet while examining differences in the rates of dental pathologies, particularly between males and females. This revealed that females consistently experienced higher rates of dental caries than males across each of the different dietary groups examined. This was true in both the in the C_3 and mixed C_3-C_4 diet groups where there were no significant differences in stable carbon isotope data between males and females, but it was also the case that females experienced higher rates of dental caries even when males had a greater consumption of maize-based products, as represented by higher $\delta^{13}C$ values. These findings indicate that the differing rates of dental caries between the sexes are unlikely due to dietary differences between men and women and much more likely to be the cause of other factors. Various factors are recognised as making women more susceptible to the development of dental caries than men, including salivary composition, quantity, and flow rate, hormonal differences, and ages of dental eruption (Lukacs and Largaespada 2006). Increased fertility rates associated with the transition to agriculture (Bocquet-Appel and Naji 2006) may also be compounding female susceptibility to poorer oral health in the C_4 diet group, given various factors relating to pregnancy are also associated with higher frequencies of dental caries (Orosz et al. 1975; Russell and Mayberry 2008; Vallianatos 2007).

The results of these analyses indicate that while increased maize consumption was an important factor in declining oral health, as measured by dental caries, AMTL and periapical cavities, it does not represent the whole picture. When controlling for diet, specifically by grouping the sample by proportions of maize in the diet, C_3 dietary group, mixed C_3-C_4 diet and C_4 diet, females consistently experienced higher rates of dental caries, indicating that other pathogenic factors related to sex are at play. The findings presented here on one hand reinforce the paradigm of declining oral health with the initial introduction of more cariogenic dietary staples that accompanied the transition to agriculture and as has been observed with this shift in various locations around the world (e.g. Cohen and Armelagos 2013). However, on the other hand, the

deeper analysis of dental caries in these Central Chilean populations alongside the existing $\delta^{13}C$ data for the same individuals provides strong evidence for other factors related to sex predisposing females to higher rates of dental caries, and reinforces recent arguments (e.g. Marklein et al. 2019; Willis and Oxenham 2013) that while diet is undoubtedly a major contributing factor to rates of dental pathologies, highlighting the importance of considering multiple factors beyond diet when understanding the pathophysiology of dental diseases.

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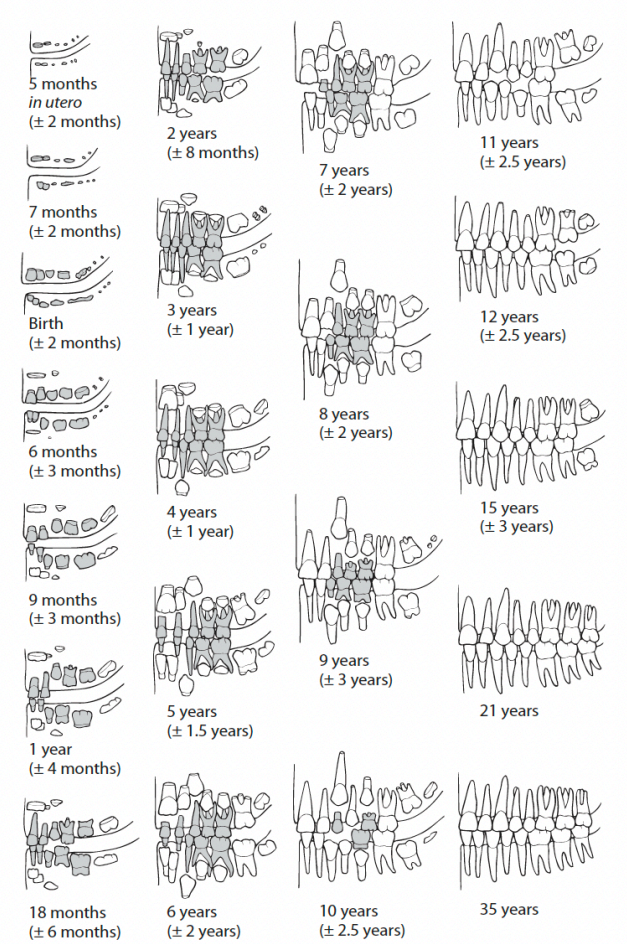


Figure 19.1 Dental development in Native Americans [adapted from Ubelaker (1989); note that data on the deciduous teeth come from non-Native Americans].

Figure 1a: Dental eruption reference chart as presented in White and Folkens (2005), and adapted from Ubelaker (1989).

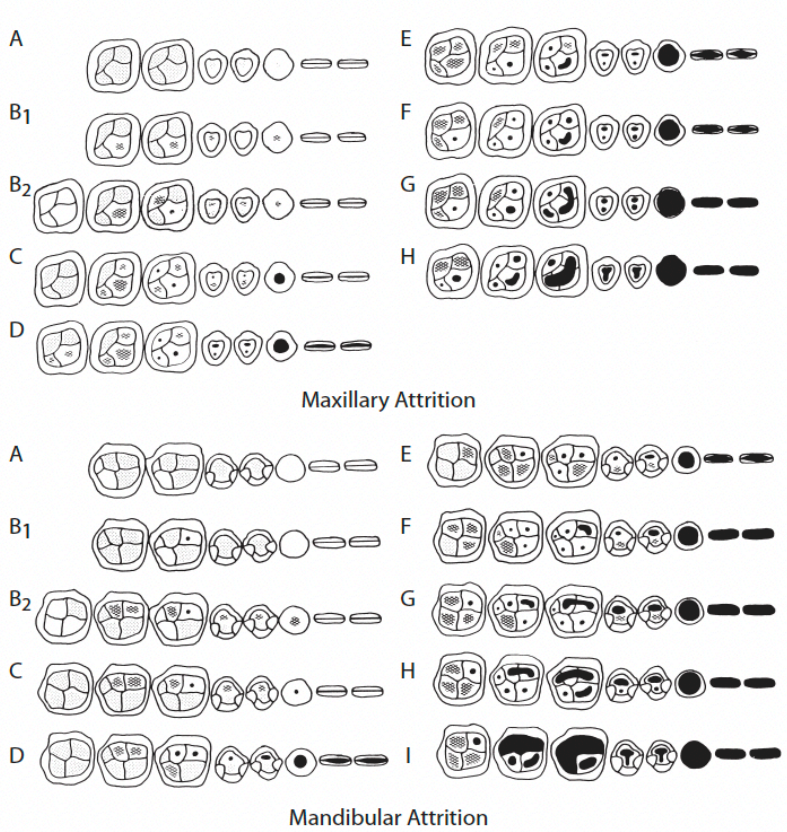


Figure 19.3 Modal tooth-wear patterns of a prehistoric Native American population from Libben, Ohio. Wear is divided into phases for right maxillary (top) and left mandibular (bottom) dentitions. Exposed dentine is shown in black. Age in years for the various phases are as follows: A, 12–18; B_1, 16–20; B_2, 16–20; C, 18–22; D, 20–24; E, 24–30; F, 30–35; G, 35–40; H (maxillary), 40–50; H (mandibular), 40–45; I, 45–55. See Lovejoy (1985) for a full description.

Figure 1b: Dental attrition reference chart for age estimation based on the method with method originally described by Lovejoy (1985) and as presented in White and Folkens (2005).

CHAPTER 6: CONCLUSIONS

1. Introduction

The transition to agriculture, from foraging to farming, is a major transition in human history, leading not only to shifts in subsistence but also to transformations in settlement patterns, population growth, and socio-political shifts. In particular, the spread of maize agriculture throughout the Americas marked a significant turning point, influencing various aspects of pre-Columbian life. Despite the well-documented significance of maize in other regions of the Americas, the Aconcagua and La Ligua Valleys of Central Chile, located at the southern frontier of maize agriculture, have been relatively underexplored in this context. The rich archaeological record in these valleys provides an excellent setting for the investigation of palaeodiet and health in the Southern Andes.

This thesis has investigated the transition to and intensification of maize agriculture in the Aconcagua and La Ligua Valleys through a bioarchaeological lens, using stable isotope analysis, radiocarbon dating, and osteological analysis of human skeletal remains from various settings along the courses of these river valleys. By applying these techniques from archaeological science, this research has advanced the understanding of pre-Columbian dietary patterns from the Early Ceramic Period (ECP) to the Late Period (LP) in Central Chile, examining when maize was first introduced into the diet, how its significance changed over time, and what impacts these shifts had on oral health. It has also addressed broader socio-political developments over this period, particularly in relation to the expansion of the Inka Empire into this region. Collectively, the findings presented within this research have achieved the main aims of this thesis, which were:

1) To investigate when maize was first introduced to the diet and how its use and significance may have varied both synchronically and diachronically;
2) To explore the impact this transition had on human oral health; and
3) To re-examine the timing of the arrival of Inka influence and expansion to this region, making up part of the southern boundary of their Empire.

2. Summary of Key Findings

2.1 DIETARY STABLE ISOTOPE ANALYSES

Dietary stable isotope ($\delta^{13}C$ and $\delta^{15}N$) analysis of human bone collagen was employed as a means of providing direct evidence of human diet, with one of the key aims of this thesis being to reconstruct dietary variations across geographic, cultural and temporal settings. Stable carbon and nitrogen isotope analyses are particularly useful for detecting diets which are based upon foodstuffs following different photosynthetic pathways. Maize, the dominant cereal crop in the Americas, follows a C_4 photosynthetic pathway, which is isotopically distinct from the C_3 pathway of the majority of wild plants in this region. No other economically significant C_4 plants have been noted in this area of Central Chile. Thus, stable carbon isotope analysis is a particularly useful way of detecting the presence of this C_4 food in human diet. The addition of stable nitrogen isotope analysis provides information about trophic levels and aids in differentiating diets based on marine ecosystems compared to those based on terrestrial resources.

The results of the stable isotope analyses were presented across two separate articles making up two separate chapters in this thesis. The first article (presented in Chapter 2 (Swift et al. 2017)) comprised a subset of the total samples analysed for this thesis. Specifically, these were the samples from the collections of the Museo de Historia Natural de Valparaíso. As a condition of access to their material, the museum requested that an article based upon the findings from the material in their collections be produced. The second article (presented in Chapter 4) builds upon the data of this initial article. It presents the data for all the material sampled for isotopic analyses for this thesis and was prepared subsequent to carrying out radiocarbon dating on an important selection of the material for the thesis sample (discussed further below), allowing for a more nuanced examination and interpretation of the stable isotope results in relation to diachronic dietary trends. In total, $\delta^{13}C$ and $\delta^{15}N$ results are presented from 242 individuals from the Aconcagua and La Ligua Valleys. The samples pertain to sites from both from coastal and inland setting and span the ECP through to the LP.

The primary focus of the isotopic analysis was to reconstruct and examine diet in the Aconcagua and La Ligua river valleys of Central Chile, with particular reference to the introduction and adoption of maize agriculture. This was achieved by interpreting the dietary stable isotope data for different geographic settings of these valleys, in particular coastal diets compared to inland diets, examining changes in diet across the different temporal periods relevant to the study (Early Ceramic Period [ECP], Late Intermediate Period [LIP] and Late Period [LP]), and comparing the isotopic data between different cultural groups described in Central Chile. Moreover, the isotopic data was evaluated alongside the new radiocarbon data presented in this thesis with a view to determining when and among which groups maize was first incorporated into the diet in Central Chile. Interpretations were also made about changes in the importance of maize as an economic staple, with particular regard to differential access to this staple resource based on sex.

A Reconstruction of Diet from the Early Ceramic Period until the Late Period in the Aconcagua and La Ligua Valleys

From the ECP through until the LP, the populations of the Aconcagua and La Ligua Valleys demonstrate a wide range of $\delta^{13}C$ values (-21.5‰ to -8.4‰) indicating considerable dietary variability during this time, from C_3-based diets with no detectable contribution from maize in the early stages of the ECP to heavily maize dependent diets from the LIP onwards. There was a noticeable diachronic increase $\delta^{13}C$ values across each of the temporal periods, tending towards greater inclusion of maize in the diet over time, with the largest shift being from the ECP to the LIP.

Distinct differences in diet were noticed in relation to the distance of sites from the coast. Moreover, coastal sites had a more constrained range of $\delta^{13}C$ values and higher $\delta^{15}N$ values than inland sites, collectively indicating the inclusion of marine resources in the diet at these sites. While $\delta^{15}N$ values are elevated at Central Chilean coastal sites relative to the inland sites, they do not reach the extremely high values that are seen in other parts of the Pacific Coast in Chile (eg. Roberts et al. 2013). The Aconcagua and La Ligua coastal diets are interpreted as having a regular inclusion of some marine resources, mostly of lower tropic levels such as shellfish and seaweeds, but also complimented by available terrestrial resources. Indeed, a switch

to some inclusion of maize in the diet, while still maintaining input from marine foods, is evident by the LIP at the coastal site of Los Coiles 136.

The $\delta^{15}N$ values for human bone collagen in this region, particularly among inland sites, are remarkably low. This is a finding that has also been noted in other Central Chilean valleys (Falabella et al. 2007; Falabella and Sanhueza 2019) and is in stark contrast to the extremely elevated $\delta^{15}N$ values observed in northern Chile (Roberts et al. 2013; Santana-Sagredo et al. 2016; Santana-Sagredo et al. 2015). It is evident that the inland populations in the Aconcagua and La Ligua were relying upon terrestrial resources in their diets. Even so, the low $\delta^{15}N$ values would suggest a very limited contribution from animal protein, or another factor that is impacting $\delta^{15}N$ values. It is possible that nutritional requirements for protein may have been met with supplementation from higher-protein plant resources, such as quinoa and legumes. Legumes are not only a good plant-based source of protein, they are also nitrogen-fixing plants and thus have depleted ^{15}N in their tissues. The regular consumption nitrogen-fixing legumes is one possible explanation for the low $\delta^{15}N$ values observed in human bone collagen. However, further exploration of the use of other edible plants endemic to Central Chile may shed further light on the observation of $\delta^{15}N$ values in human bone collagen in this region.

The Adoption of Maize Agriculture

Isotopic data from human bone collagen in the Aconcagua and La Ligua Valleys demonstrated a clear, but gradual increase in $\delta^{13}C$ values over time, indicating that the transition to maize agriculture was not a sudden event and likely occurred over several centuries before ultimately becoming the dominant staple crop in the region. The transition from a C_3-based diet to the introduction of some maize was seen during the ECP. Examination of the $\delta^{13}C$ data for the individuals with radiocarbon dates suggests this transition likely took place ca. AD 450-600. From about ca. AD 600 onwards the inclusion of maize continued to gradually increase over time, reaching its peak in the Aconcagua and La Ligua Valleys around the LIP/LP transition ca. AD 1300-1400. The timing of this peak in maize consumption likely reflects an intensification of maize farming in the Aconcagua Valley with the introduction of new technology and irrigation alongside assimilation with the

expanding Inka Empire. The trends observed in the Aconcagua and La Ligua Valleys largely mirror those in neighbouring valleys to south, the Maipo-Mapocho and Cachapoal (e.g. Falabella et al. 2020), with some local variations. However, the analysis presented in this thesis alongside radiocarbon dates for the same individuals has allowed for better resolution of the timing of the transitions in dietary practices and maize use.

Not Just an Economic Staple? Indications of a Broader Social Significance

Dietary isotopic analyses also revealed an interesting social dimension of maize consumption in the Aconcagua and La Ligua Valleys in that males were consuming a greater proportion of maize-based foods than females in the later periods (LIP and LP). This is a pattern that is also reflected in the Central Chilean valleys to the south of this study area (Falabella et al. 2020). In Andean societies maize was consumed in various form, such as dried, popped, roasted, boiled, mashed, and fermented as *chicha* (Staller 2010; Staller et al. 2006; Valcárcel 1946). The importance of maize beyond mere sustenance, and extending to a central role in social, cultural and religious contexts is well documented in the Andes. *Chicha*, in particular, was central to Andean social, political and ritual practices (MacCormack 2004). The Inka further emphasised the role of maize in the political economy, tied to reciprocity, tribute and labour obligations during the LP (Classen 1993; Murra 1973; Staller 2006; 2008; Staller and Thompson 2002). The greater access to maize experienced by males during the later periods in Central Chile is inferred to be a reflection of gender roles in these communities, possibly linked to the broader social, cultural, political or religious significance of maize in the Andes.

Contribution

The stable isotope analyses presented in this thesis make a substantial contribution towards understanding the adoption and intensification of maize agriculture in Central Chile, particularly in the Aconcagua and La Ligua Valleys. Integrating dietary isotopic analyses and radiocarbon dating, this research reconstructs dietary patterns across geographic, cultural and temporal settings from the ECP to the LP in the Aconcagua and La Ligua Valleys, and successfully addresses the following additional aims:

a. Determine when and among which groups maize was first incorporated into the diet in Central Chile.

b. Ascertain whether the transition to maize agriculture was rapid or gradual.

c. Identify changes in the importance of maize as an economic resource and make inferences about whether maize was solely an economic staple, or if differential access to maize within sites implies other significance as a ritual or luxury food. More specifically, seek to examine differential access based on sex.

The large body of isotopic data presented in this thesis contributes to a greater understanding of diet and subsistence strategies in the region. This research has provided insight into the variabilities in diet and maize adoption across various settings in the Aconcagua and La Ligua Valleys. Noting differences in geographic settings, particularly the distinction between inland and coastal diets, and tracing a gradual shift from C_3-based diets to the increasing reliance on C_4 resources. The new information presented in this thesis indicates that the transition to incorporating a significant enough proportion of maize in the diet to be detected by stable carbon isotope analysis occurred ca. AD 450-600, in ECP communities. These findings refine the timeline of maize adoption in Central Chile, offering a more precise understanding of this transition. The isotopic evidence also highlights a differential access to maize observed during the later periods, particularly in relation to sex, suggesting that maize functioned as more than an economic staple, likely reflecting additional social, cultural, political or religious importance associated with this resource in the pre-Columbian Andes. By providing new insights into dietary patterns from the ECP until the LP, this thesis adds to the understanding of regional variation in pre-Columbian subsistence patterns and contributes to discussions about the broader social significance of maize and the intersection of food, status and social identity in pre-Columbian Andean communities.

2.2 RADIOCARBON DATING IN THE ACONCAGUA AND LA LIGUA VALLEYS: DIACHRONIC DIETARY CHANGES, INKA EXPANSION AND THE TRANSITION TO THE LATE PERIOD

Radiocarbon dating was employed to help with refining the chronology of the Aconcagua and La Ligua Valleys. In particular, to establish an initial chronology for the largest cemetery in the Aconcagua at site of Estadio de Quillota, as well as the large cemetery at Valle Hermoso in La Ligua Valley. The suite of radiocarbon dating also served an additional purpose of investigating the timing of two significant events in this region: the introduction of maize to the diet, and the arrival of Inka Influence, which is coeval with the transition to the LP in Central Chilean archaeology.

In total 35 new AMS radiocarbon dates have been presented in this thesis, primarily from the two largest cemetery sites at Estadio de Quillota (*n*=17) in the Aconcagua Valley and Valle Hermoso (*n*=15) in La Ligua Valley, but also from some of the upper basin sites (*n*=3). The new dates from these sites all reflect a similar pattern, identifying two distinct phases of use. An earlier phase of use, coincident with the Initial Ceramic Communities at the start of the ECP in Central Chile:

- At Estadio de Quillota in the Aconcagua Valley: 339-196 cal BC to cal AD 128-339 (OxA V-2735-19 and V-2737-44)
- At Valle Hermoso in La Ligua Valley: cal AD 62-216 (OxA V-2735-20)
- At the Upper Basin site of Fundo Las Palmas: cal AD 251-409 (UCIAMS 206833)

And a later phase of use, coinciding with the terminal stages of the LIP and the beginning of the LP, during which time Aconcagua, Diaguita and Inka cultural influences are observed in the region:

- At Estadio de Quillota in the Aconcagua Valley: cal AD 1280-1387 to 1413-1458 (OxA V-2730-55 and V-2735-18)

- At Valle Hermoso in La Ligua Valley cal AD 1276-1379 to 1316-1426 (UCIAMS 206825 and OxA V-2735-22)
- At the Upper Basin sites, El Sauce and Puente el Castillo in the Los Andes area: cal AD 1227-1284 to 1408-1442 (UCIAMS 206831 and 206832)

Dietary Changes

The two phases identified by the radiocarbon dates also correspond to distinct diets and are significantly correlated with a shift from lower to higher $\delta^{13}C$ and $\delta^{15}N$ values ($\delta^{13}C$ $p<0.000$, $\delta^{15}N$ $p<0.000$). The earlier diet, determined by $\delta^{13}C$ and $\delta^{15}N$ analysis, suggests a reliance on C_3 terrestrial plant resources, with little input from animal proteins and possible protein supplementation with nitrogen-fixing legumes, during the ICC and early stages of the ECP. The later diet, around the transition from LIP to LIP, demonstrates a heavy reliance on maize-based produce, indicating that maize agriculture was underpinning subsistence strategies by the end of the LIP.

It can be seen that a distinct dietary shift from foraging to farming occurred between the earlier phase and the later phase identified at these sites, the gap of around ca. 800-900 years, from about cal AD 409 to cal AD 1227 between these phases leaves much of the ECP unrepresented in the Aconcagua and La Ligua Valleys in terms of radiocarbon dates, limiting more nuanced estimations of when or how quickly this shift from C_3 to C_4 resources occurred. However, combining the data from the Aconcagua and La Ligua Valleys with isotopic and radiocarbon data from the Maipo-Mapocho and Cachapoal Valleys, treating the region of Central Chile as a whole (as discussed further in the isotope analysis chapters [chapters 2 and 4]) indicates the shift to more regular inclusion of maize in the diet likely occurred after ca. AD 600.

Inka Expansion and Transition to the Late Period

A further contribution of the radiocarbon dating included in this thesis has been in revisiting the timing of Inka expansion towards what became the southern frontier of their Empire (Swift et al. 2022). Traditionally, the southern expansion of the Inka has been based on a date of AD 1471 derived from ethnohistoric sources

(Rowe 1944; 1945). However, nowadays many sources place this some decades earlier at ca. AD 1450 (Uribe and Sánchez 2016). In Central Chile, the arrival of Inka influence is also the defining feature of the transition from the LIP to the LP. However, there has been growing evidence from frontier regions of the Empire to suggest that the southern expansion may have taken place several decades earlier (Alconini 2016; Cornejo 2014; Hermosilla et al. 2005; Mundt and Marsh 2021; Ogburn 2012; Raffino and Stehberg 1999; Rodríguez et al. 1993; Sánchez Romero 2004; Williams and D'Altroy 1998), which has been followed by calls for more radiometric dating of Inka contexts from frontier zones of the Empire (Marsh et al. 2017; Ogburn 2012).

The radiocarbon dates presented in this thesis from local Inka phase burial contexts at Estadio de Quillota challenge the traditional historical timeline of Inka expansion (Swift et al. 2022). Chronometric modelling of the new dates from EDQ suggests that Inka influence reached the region up to a century earlier, possibly as early as the late 14th or early 15th century. In fact, the modelled LP dates from EDQ even predate those from other sections of the southern frontier located in Argentina (Marsh et al. 2017), and are in agreement with a recent assertion that the Aconcagua Valley may have been an initial nucleus for the spread of Inka influence in the southern reaches of their Empire (Mundt and Marsh 2021). It is now proposed that Inka expansion on the southern frontier may have occurred in two phases: an initial phase of interaction and cultural influence, with technological exchange and Inka iconography appearing in material culture, followed by a secondary phase of consolidation and occupation, consisting of a more direct physical presence and the construction of Inka infrastructure and architecture in the Aconcagua Valley.

The early arrival of Inka influence in Central Chile has important implications, not just for the Empire's expansion into this region, but also regarding the start of the Imperial phase in Cuzco (AD 1438 according to traditional chronology (Rowe 1944)), as well as the order in which the Inka expanded into the four quarters of its Empire. The findings presented in this thesis support an argument that the traditional Inka chronology and the sequence of expansion need to be reconsidered, with view to a major revision based on evidence from radiometric dating.

Contribution

The radiocarbon results from this thesis provide a substantial contribution to the chronology of the region. Previously, there were no radiocarbon dates from La Ligua Valley, and a smattering from the Aconcagua which was noticeably sparse in the inland valley (Swift et al. 2022). Until now, the chronology of Central Chile has been largely defined by ceramic typochronologies supported by thermoluminescence dates. This is problematic, however, as serious discrepancies have been noted for TL dates in Chile (Pavlovic et al. 2012; Schiappacasse et al. 1991; Swift et al. 2022). Indeed, a recent critique of the reliability of TL in the Southern Andes concluded that ^{14}C dates should be used instead to support cultural chronologies (Marsh et al. 2021).

By collating the new radiocarbon dates with previous dates from the Aconcagua, a sequence of use spanning approximately 7000 years has been established. The earliest dates derive from shell middens on the coast (S-Bato 1 5561–5474 cal BC; Beta128761) (Seelenfreund and Westfall 2000) and the latest to an Inka site in the Upper Basin (El Tigre cal AD 1501–1649; UGAMS5980) (Pavlovic et al. 2012). The new radiocarbon dates from EDQ and the Upper Basin sites fall within the constraints of the overall occupation sequence for the Aconcagua Valley, as do the new dates from Valle Hermoso in La Ligua Valley.

These findings collectively contribute to refining the understanding of Central Chile's prehistory, especially regarding the timing of cultural and agricultural transitions. The radiocarbon dating presented here has underpinned and contributed to all of the thesis aims, but has particularly served to address the aim relating to chronological questions: To improve the radiocarbon chronology for the prehistory of the Aconcagua and La Ligua Valleys with particular reference to two major transitions: the spread of maize agriculture, and the arrival of Inka influence. This has included:

d. Establishing a radiocarbon chronology for Estadio de Quillota, the largest cemetery site in the Aconcagua Valley.

e. Refining the timing for the expansion of maize agriculture in this region.

f. Re-evaluating the timing of the expansion of Inka influence into this region.

Altogether, these findings not only refine the regional chronology but also offer critical perspectives on how Central Chile fits into larger narratives of agricultural and imperial expansion, demonstrating the region's significance in broader Andean history.

2.3 DENTAL PATHOLOGIES

Dental pathologies were examined and recorded for the Aconcagua and La Ligua Valley populations for the purpose of understanding how the transition to maize agriculture impacted oral health. Taking a palaeopathological approach to analysing dental conditions, the aim was not only to explore the relationship between diet, particularly maize consumption, and dental lesions, but also to examine the variability in oral health between the sexes both before and after the adoption of maize as a dietary staple. Since tooth enamel does not remodel and teeth are typically well preserved archaeologically, dental lesions can serve as an excellent source of information about diet, health, and cultural practices in past populations (Hillson 2001; Lukacs 1989).

Dental pathologies such as carious lesions, ante-mortem tooth loss (AMTL), and periapical cavities can offer valuable insights into subsistence strategies and dietary changes (Hillson 2001; Roberts and Manchester 2005). The oral cavity plays an important role in human health and serves as a proxy for diet, as teeth process food for nutrition, interacting directly with both the environment and diet. It has long been recognised that the adoption of agriculture led to an initial decline in population health (Cohen and Armelagos 1984; Cohen and Armelagos 2013; Steckel and Rose 2002; Turner 1979). In general, the inclusion of fermentable carbohydrates like maize and other cereal crops as dietary staples during the agricultural transition resulted in an increase in dental lesions (Leverett 1982; Rowe 1975). These dental pathologies, such as caries, AMTL and periapical cavities, can impair chewing and reduce appetite, which in turn affects nutrition and overall health. However, there are other important factors beyond diet that can also impact oral health. Several of these additional factors are related to biological sex and can predispose females to poorer oral health, such as reduced salivary flow rate and smaller gland size leading to less effective pH buffering and antimicrobial action, and hormonal fluctuations like increased oestrogen, which can result in a drier, more acidic oral

environment, contributing to enamel erosion and a higher incidence of carious lesions (Lukacs and Largaespada 2006).

Data were recorded for dental caries, periapical cavities and ante-mortem tooth loss from 177 individuals with permanent dentition from the various Aconcagua and La Ligua Valley collections. The collections pertained to both coastal and inland settings, and encompassed the ECP, through the LIP and into the LP (ca. 300 BC – AD 1536). The patterns of these lesions were analysed in conjunction with the available dietary stable isotope data to investigate the connection between the diet and these markers of oral health. They were also examined for differences between the sexes.

Dental Health and Dietary Changes

Utilising the available stable isotope data, the sample was divided into dietary groups based on a coastal or inland diet, and the proportion of maize consumption. This resulted in five dietary groups, two for the coast (marine and marine-C_4) and three for the inland populations (predominantly C_3, mixed C_3-C_4, and C_4). Analyses of the dental pathologies alongside the dietary groups revealed a rise in dental caries, AMTL, and periapical cavities following the introduction of maize as a dietary staple.

The new data from the Aconcagua and La Ligua Valleys provided here demonstrate the impact on dental health of the shift to maize as a dietary staple. Patterns of increased dental diseases were seen in both inland and coastal populations, as well as across age groups. Dietary isotope data from the same Central Chilean population show that a transition to more regular maize consumption is an important factor related to an increase in the occurrence of the recorded dental lesions. Given the known cariogenicity of maize as a staple food, it is unsurprising that maize agriculture has likewise been observed to follow the same pattern of worsening dental health alongside the increased exploitation of this resource. The new results from the Aconcagua and La Ligua Valleys conform to widely observed global patterns of declining oral health alongside the transition to agriculture (Cohen and Armelagos 2013; Steckel and Rose 2002; Turner 1979), as well as

patterns observed in other South Central Andean populations to the north (Alfonso et al. 2007; Kelley et al. 1991; Watson et al. 2010).

Not Only Diet: A Difference Between the Sexes

Even though diet is undeniably an important factor in the pathogenesis of various dental pathologies, there are a number of other factors that can also create a susceptibility to poorer oral health, but are often overlooked in bioarchaeology. Several of these factors are related to biological differences between the sexes. For example, dental eruption occurs slightly earlier in females, there are also differences in salivary gland size, saliva flow rate and biochemistry between males and females (Dodds et al. 2005; Percival et al. 1994). Hormonal differences and particularly pregnancy-related hormone changes are also linked to increased susceptibility to developing dental caries and other dental lesions (Delman 1955; Laine 2002; Silk et al. 2008). The relationship between these agents and poorer dental health has been observed in clinical settings (Carlos and Gittelsohn 1965; Ferraro and Vieira 2010; Galvão-Moreira et al. 2018; Shaffer et al. 2015), yet when higher rates of dental caries are observed in females in a bioarchaeological setting, they are often interpreted as the result of a presumed sex-based dietary difference alone (Hillson 2008; Larsen 1997).

Further important changes took place around the transition to agriculture in addition to shifts in diet, for example, changes in settlement patterns, increased sedentism, as well as significantly expanding population numbers along with increased fertility and mortality rates (Bocquet-Appel 2002; Bocquet-Appel and Naji 2006). Given the link between increased susceptibility to dental caries during pregnancy, it has been suggested that such an increase in fertility rates coeval with the adoption of agriculture would compound an already higher frequency of dental caries experienced by females. This effect has been demonstrated around the Neolithic transition in Vietnam (Willis and Oxenham 2013) and indeed is also observed in the Aconcagua and La Ligua Valleys of Central Chile supported by the data presented in this thesis.

Because stable isotope data for the Central Chilean sample were available, it was possible to examine variations in the rates of dental pathologies between males and females while controlling for diet. Indeed,

females had consistently higher frequencies of both dental caries and AMTL than males across all dietary categories studied. This was true in the predominantly C_3 dietary group, where males and females had indistinguishable diets based on isotopic values. However, in the mixed C_3-C_4 and the C_4 dietary groups, where males consumed a higher proportion of cariogenic maize than females, as indicated by higher $\delta^{13}C$ values (Chapters 2 and 4), the females still experienced higher rates of dental caries and AMTL despite consuming less maize than the males. The findings presented in this thesis provide strong evidence that there are factors other than just diet that are contributing to this trend. It is proposed that the difference between males and females is due to other sex-related factors that can predispose females to poorer oral health and exacerbated with the transition to agriculture due increasing fertility rates.

Contribution

The study of dental pathologies can reveal important information about the health status and food habits of past populations. The new data for the Aconcagua and La Ligua Valley presented in this thesis not only contributes to an understanding of impact of a cariogenic dietary staple such as maize on dental health, but also challenges simplistic interpretations of sex-based differences in oral health. In doing so, the dental palaeopathologies chapter addressed one of the main thesis aims, which was to understand how the adoption of maize agriculture impacted oral health in the Aconcagua and La Ligua Valleys. This included:

a. Exploring the relationship between diet, specifically maize consumption, and rates of dental caries, ante-mortem tooth loss and periapical lesions.

b. Examining the variability in dental lesions between sexes across different dietary categories, before and after the adoption of maize as a dietary staple.

The dental pathology findings presented in this thesis add to an understanding of how subsistence practices influence health outcomes and how these changes can be represented by the occurrence of dental lesions. The study found that maize consumption was a contributing factor to poorer oral health, including dental

caries, AMTL and periapical cavities. However, comparisons within dietary groups also demonstrated that females were consistently affected by a higher rate of caries and AMTL than males. For dental caries, this difference between the sexes widened even further after the adoption of maize agriculture, with females in the C_4 dietary group experiencing a caries prevalence 2.5 times that of males.

Overall, these findings contribute to a broader understanding of how agricultural transitions affected health and support the hypothesis that maize agriculture had deleterious effects on dental health. The results also strongly point to the impact of intrinsic, sex-based, factors influencing susceptibility to dental lesions as well as other factors that are indirectly associated with the intensification of agriculture, such as increased fertility and birth rates that co-occur alongside a transition, and not just the increase of cariogenic foods (maize) in the diet alone. This suggests that the relationship between diet, subsistence strategy and dental health is complex, and other possible pathogenic variables, beyond only diet, should be considered when evaluating dental pathologies in a bioarchaeological context. These findings suggest that future bioarchaeological research should continue to explore the manifold interactions between diet, biology, and health outcomes, particularly in relation to sex-specific responses to transitions in subsistence strategies.

3. Limitations of the Research

There is an abundance of bioarchaeological material housed in Central Chilean museums which are open to proposals of collaborative research. However, the biggest limitation encountered when working with this material was the variability in available contextual information. Indeed, several of the curators are frustrated by the condition and lack of context with which some material has been deposited in their holdings, as they naturally recognise the cultural significance of these collections. Some collections are accompanied by detailed excavation reports, others comprise remains that have simply been collected by members of the public or workers when they have been disturbed during earthworks, and others have been salvaged under difficult conditions with urgent time constraints imposed upon archaeologists due to the competing priority of encroaching development. The latter was the case with the large cemetery site at Estadio de Quillota.

The lack of stratigraphic information and individual mortuary contexts somewhat hampers interpretations of new data for these collections. The piecemeal contextual background was further compounded by a relative scarcity of radiocarbon dates for the two study valleys, and the realisation that thermoluminescence dates are likely to be unreliable in this region (Marsh et al. 2021). Nonetheless, conservative relative dating was able to be utilised to assist with data analysis for this thesis, alongside careful selection of samples for the new radiocarbon dates.

This, at times frustrating, limitation of patchy contextual information nevertheless serves to highlight one of the major contributions of this thesis: reconstructing some information for each of the individuals held in these collections. Osteological assessments of biological profile were carried out for 416 individuals who were originally examined during the data collection stage of this research, assigning estimations of sex and age to each individual where it was possible based on the preservation and condition of their remains. Bone samples appropriate for stable isotope analysis were collected from 307 of the individuals and funding obtained for radiocarbon dating of a subset of 35 individuals. The data resulting from stable isotope analyses, radiocarbon dating and osteological examinations of these pre-Columbian people from the Aconcagua and La Ligua Valleys has been returned to the relevant holding museums. While individual mortuary contexts may have been lost for many of the human remains housed in these collections, the provision of the aforementioned data restores some context for these individuals and can now serve as a basis for future research. Aside from the key findings presented in this thesis, and summarised above, it is hoped that the provision of this data also establishes a necessary foundation and starting point for further bioarchaeological reconstructions of the lifeways, cultures and people who inhabited this fascinating region in prehistory.

4. Suggestions for Future Research

The predominant recommendation for further research in this area would be the application of additional radiocarbon dating. The current chronological framework that underpins much of the work in Central Chile,

following different cultural periods, is largely based on ceramic typo-chronologies with the support of questionable thermoluminescence (TL) dates. Reliance on this framework is reminiscent of cultural history schemes, where "pots = people", dominant in archaeology before the rise of processualism and post-processualism (Hodder and Hutson 2003; Renfrew and Bahn 2018; Trigger 2006). There are some ambiguities with this system (some of which are highlighted in Chapter 3 and Swift et al. (2022)), and a shift towards a more objective and precise chronology based on radiocarbon dating would enhance the understanding of important social, cultural and economic transitions in this region and provide a stronger foundation for future archaeological work.

The radiocarbon dates presented in this thesis were predominantly directed towards establishing a chronology for the two largest cemetery sites in the Aconcagua and La Ligua Valleys (Estadio de Quillota and Valle Hermoso, respectively) with the addition of a few radiocarbon dates from the Upper Basin, around the Los Andes area on the western slopes of the Andes mountain range (Swift et al. 2022 and Chapter 4). Improved chronological resolution for the vast archaeological sites and bioarchaeological material in Central Chile would be extremely beneficial towards allowing for more precise investigation of specific research topics. In particular:

1) Developing a radiocarbon chronology for other cemetery sites in the Aconcagua and La Ligua Valleys. The dates presented in this thesis are constrained to an earlier and a later phase of use (earlier phase median dates ~387 cal BC to cal AD ~322 [OxA V-2735-19 and UCIAMS 206833], and later phase median dates cal AD ~1245 to ~1423 [UCIAMS 206831 and OxA V-2735-18]). Investigating the chronology of other sites in these valleys will shed more light on the ca. 900 year gap between these phases and provide a broader understanding of occupation sequences, land use and settlement patterns in these valleys.

2) The later phase of use identified by the new radiocarbon dates for the Aconcagua and La Ligua Valleys align with dates ranging from cal AD 1210–1275 to cal AD 1320-1425 for a recently identified

migration of farmers into the Uspallata Valley in Argentina (Barberena et al. 2024; Barberena et al. 2020). The Uspallata is located on the eastern side of the Andes mountain range and is connected via a highland pass to the Aconcagua Valley on the western side. A reasonable hypothesis would be that the later phase of use identified in the Aconcagua and La Ligua Valleys and linked with a maize-dependent diet (see Chapter 4), is a part of a larger pattern of migration of maize farmers into the Southern Andes. This hypothesis could be tested with strontium isotope analysis ($^{87}Sr/^{86}Sr$) of human bone and tooth samples dated to the same period and utilising baseline $^{87}Sr/^{86}Sr$ data that is already available for Central Chile (Barberena et al. 2021; Barberena et al. 2017).

3) Paired radiocarbon dating of human bone collagen from burials that already have TL dates from mortuary ceramics could usefully test the reliability of TL dating in the Aconcagua and La Ligua Valleys. Serious concern has been raised over the reliability of TL in the Southern Andes (Marsh et al. 2021), yet much of the chronology developed for Central Chile has been supported by this dating method. There are over 150 TL dates from the Aconcagua and La Ligua, and of those there are 20 from the sites of Valle Hermoso, Escuela de Placilla and Los Coiles 136 that could be paired with radiocarbon dates of human bone collagen.

The isotopic research presented in this thesis lays an important foundation and represents the tip of an iceberg in terms of potential further investigations. Logical next steps for isotopic research in this area would include further investigations regarding palaeodiet, and new questions around mobility and migration. For example:

4) The addition of systematic archaeobotanical investigations in the Aconcagua and La Ligua Valley would strongly complement the palaeodietary reconstructions of the human data for these valleys. Two areas that would be particularly useful to explore include the investigation of the low $\delta^{15}N$ values observed in human bone collagen across Central Chile and other potential contributors to elevated $\delta^{13}C$ beyond maize.

a) Systematic archaeobotanical study accompanying further excavations in this region may be able to provide an estimate of relative proportions of legumes among other edible plants in different contexts. Further exploration of $\delta^{15}N$ of edible plants endemic to this region would also be useful. The botanical isotopic data presented in this thesis included the first measurements of $\delta^{15}N$ for samples of edible plants in Central Chile. Indeed, some of these plants displayed lower $\delta^{15}N$, which if consumed in large enough quantities, may be impacting upon the $\delta^{15}N$ observed in human bone collagen. This research has identified two species of endemic edible plants that have potential as important dietary resources in this region (Aldunate et al. 1988; Quiroz and Belmar 2004; Vivar 1988 [1558]) and would be of interest for further investigation: *coquito* (miniature Chilean coconuts [*Jubaea chilensis*]) and *peumo* (Chilean acorn [*Cryptocarya alba*]). The edible nuts from these plants presented low $\delta^{15}N$ (see Chapter 4) and both are endemic to Central Chile where low human $\delta^{15}N$ values were observed.

b) Further archaeobotanical investigations could also explore the possibility of other edible plants in Central Chile that may contribute to elevated $\delta^{13}C$ in humans from this region, including possible additional C_4 resources or CAM plants. While no other edible C_4 plants have been identified in significant quantities in archaeological contexts in Central Chile to date, it is important to consider this possibility. Important C_4 crops, such as amaranth (*Amaranthus caudatus*), and the prickly pear (*Opuntia ficus-indica*), a CAM plant with elevated $\delta^{13}C$, have been recorded elsewhere in the Andes (Cadwallader et al. 2012; Llano 2009; Llano and Ugan 2014).

5) Childhood nutrition, and in particular breastfeeding and weaning practices could be further examined. Data regarding breastfeeding and weaning practices can reflect the broader subsistence strategies of a population, childhood health, cultural practices, population dynamics and fertility rates. These questions could be explored comparing the $\delta^{15}N$ of bone collagen of infants to those who survived into adulthood (Tsutaya and Yoneda 2015). The addition of incremental analysis of $\delta^{13}C$

and $\delta^{15}N$ of dentine would provide even further resolution to such questions (Beaumont et al. 2015; Clark et al. 2016). The cemetery at Valle Hermoso, with a high proportion of infants and children, presents a suitable sample to investigate breastfeeding and weaning practices in pre-Columbian agro-pastoral communities of Central Chile.

6) Regional mobility and migrations could also be explored using $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses of bone apatite or tooth enamel. Greater resolution has been demonstrated with $^{87}Sr/^{86}Sr$ in the Southern Andes (Barberena et al. 2021), and, as discussed above, could be used to determine whether the Aconcagua and La Ligua Valleys were also part of the migration of maize farmers as seen on the Argentine side of the Southern Andes (Barberena et al. 2024; Barberena et al. 2020). However, mobility from east to west, along the river valleys, could also be evaluated with $\delta^{18}O$ to test hypotheses related to seasonal migrations related to resource availability within the valleys (e.g. Falabella et al. 2007; Falabella et al. 2020).

5. Final Remarks

The findings presented in this thesis advance our understanding of the transition to maize agriculture in the Aconcagua and La Ligua Valleys of Central Chile, and, more broadly, the Southern Andes, but also highlight the complicated relationship between diet, health and social structure in pre-Columbian societies. Combining stable isotope analysis with radiocarbon dating and osteological data, the collective findings presented here reconstruct dietary variability from the ECP to the LP in Central Chile, including the gradual introduction of maize as a staple crop. Moreover, the evidence of differential access to maize between males and females indicates a significance of the resource that extends beyond its economic use. The substantial effect of the transition to maize agriculture on dental health in these valleys, alongside patterns of different experiences of dental health between the sexes, underscores the importance of considering not just dietary influences on dental health, but also social, cultural and biological factors. Additionally, new radiocarbon dates have refined the chronology for these valleys and provided evidence that the Inka Empire had

expanded its reach to this southern frontier earlier than previously assumed. The presence of Inka burial contexts in the Aconcagua Valley by the late 13th or early 14th century provides evidence to revise our understanding of both the timing and nature of Inka expansion.

This thesis refines our understanding of the role of maize agriculture in Central Chile and contributes to broader discussions of how agricultural transitions reshape human societies, lifeways and health. The interaction of diet, socio-cultural practices and external influences discussed in this research serves as a contribution to Andean archaeology and global studies of agricultural transitions, demonstrating the unique power of bioarchaeology to illuminate the lives of past peoples.

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APPENDIX A: ORIGINAL SPANISH LANGUAGE PUBLICATION OF CHAPTER 2 (SWIFT ET AL., 2017)

Swift JL, Oyanedel-Perez J, Abarca-Labra V, Fuenzalida-Bahamondes N, Schulting RJ. 2017. Pre-Columbian Diet in the Aconcagua Valley, Central Chile: Evidence from Stable Isotope ($\delta^{13}C$ and $\delta^{15}N$) Analysis and Dental Caries. Society for American Archaeology 82nd Annual Meeting; April 2017; Vancouver.

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ANALES



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ANALES DEL MUSEO DE HISTORIA NATURAL DE VALPARAÍSO
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DIETA PREHISPÁNICA EN LA REGIÓN DE VALPARAÍSO, CHILE CENTRAL: EVIDENCIA DEL ANÁLISIS DE ISÓTOPOS ESTABLES DE CARBONO Y NITRÓGENO DE COLÁGENO ÓSEO HUMANO DE LAS COLECCIONES DEL MUSEO DE HISTORIA NATURAL DE VALPARAÍSO

Jaime Swift[1], Juanita Oyanedel Pérez[2] & Lilian López Labbé[3]

Resumen: El objetivo de esta investigación fue aportar nueva información sobre las prácticas dietéticas prehispánicas en la región de Valparaíso utilizando evidencia proveniente del análisis de isótopos estables de carbono (δ13C) y nitrógeno (δ13N) de colágeno óseo humano. Se obtuvieron muestras de restos óseos humanos de 24 individuos previamente recuperados de varios sitios arqueológicos de la región. Los resultados demostraron variabilidad en las prácticas dietéticas en diferentes contextos temporales (desde el Periodo Alfarero Temprano al Tardío) y geográficos (costeros vs valle interior), particularmente con respecto al consumo de C4 (maíz) o de recursos marinos. La amplia gama de valores de δ13C del material estudiado apunta a una mayor inclusión del maíz en la dieta a través del tiempo. También sugieren que la dieta local costera incluyó una mezcla de alimentos terrestres complementados con recursos marinos, de niveles tróficos más bajos como moluscos o algas marinas. Mientras que los bajos valores de δ15N para los grupos del interior, sugieren una dieta terrestre probablemente baja en proteínas animales o bien que incluye el consumo regular de leguminosas fijadoras de nitrógeno.

Palabras Claves: Paleodieta, restos oseos humanos, Bato, Llolleo, Aconcagua, Inka.

Abstract: The objective of this research was to provide new information regarding prehistoric dietary practices in the Valparaíso region, using evidence from stable carbon (δ13C) and nitrogen (δ13N) isotopic analyses of human bone collagen. Samples were obtained from human skeletal remains of 24 individuals previously recovered from various archaeological sites within the region. The results demonstrated variability in dietary practices over different temporal (Early Ceramic through to Late) and geographic settings (coastal vs inland), particularly regarding the consumption of C4 (maize) or marine resources. A wide range of δ13C values from the material studied particularly points towards an increasing inclusion of maize in the diet over time. The new isotopic data also suggest that the local, coastal diet included a mixture of terrestrial foods supplemented by marine resources, especially those of lower trophic levels such as molluscs or seaweeds. Whereas low δ15N values for inland groups, infer a terrestrial diet that may have either been low in animal proteins or included regular consumption of nitrogen-fixing legumes.

Keywords: Paleodiet, human remains bones, Bato, Llolleo, Aconcagua, Inka.

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INTRODUCCIÓN

En Chile central las prácticas dietéticas prehispánicas han sido descritas como una característica de los diferentes grupos culturales de la zona (Falabella, et al. 2007). Sin embargo gran parte de la investigación paleodietaria existente en Chile central se basa en en sitios de la zona de Santiago y Rancagua (Falabella, et al. 2007; Falabella, et al. 2008; Planella, et al. 2014; Sanhueza y Falabella, 2010; Tykot, et al. 2009). Desde el Periodo Alfarero Temprano (PAT) en adelante, se han observado diversas prácticas alimentarias y de subsistencia, entre ellas la existencia contemporánea de grupos de cazadores-recolectores y agricultores incipientes, la introducción del maíz domesticado y la posterior intensificación de prácticas agrícolas.

Una parte importante de las inferencias e interpretaciones previas sobre la dieta en la región de Valparaíso, en Chile central, se han basado en evidencias arqueobotánicas y zooarqueológicas (Belmar, et al. 2013; Carmona, et al. 2001), patrones de paleopatología dental (Arriagada y Oyanedel, 2014; Henríquez, 2006) y el potencial paleoambiental de la región (Ávalos y Saunier, 2011). Del mismo modo, el análisis isotópico estable de esqueletos humanos puede aportar evidencia de la dieta y las estrategias de subsistencia del pasado, distinguiendo entre los diferentes recursos consumidos, como los alimentos marinos frente a los terrestres y las plantas C4 (maíz) versus las plantas C3 (quínoa, papas, frutas). Esta investigación presenta los resultados de los análisis de isótopos estables de carbono (δ13C) y nitrógeno (δ13N) de colágeno de hueso humano de las colecciones bioantropológicas del Museo de Historia Natural de Valparaíso (MHNV), con el objetivo de aportar nueva información sobre la dieta prehispánica en la región de Valparaíso.

1 ANTECEDENTES GENERALES

La región de Valparaíso, en la zona central de Chile, se extiende desde los 31o55'S hasta los 33o38'S y marca la transición de los desiertos del norte a un paisaje más fértil en la zona central de Chile. La región está atravesada por varios sistemas fluviales, que incluye la gran cuenca fluvial del Aconcagua. Asimismo esta área varía de oeste a este e incluye distintas zonas geográficas: la costa del Pacífico, la cordillera de la costa, el valle interior (o depresión intermedia) y la cordillera de Los Andes (Fig. 1). En tanto la vegetación nativa dominante en las zonas habitables consiste en arbustos y bosques esclerófilos (Bambach, et al. 2013; Moreira-Muñoz, 2011).



Figura 1: Mapa del área de estudio que muestra la ubicación de los sitios arqueológicos que incluye el material para este estudio.

La zona está sujeta a un clima mediterráneo con veranos secos e inviernos húmedos. Las condiciones climáticas actuales han permanecido prácticamente iguales en los últimos 3.000 años, con variaciones estacionales e interanuales de las precipitaciones, influenciadas por las fluctuaciones de la Oscilación del Sur El Niño (Jenny, et al. 2002; Villagrán y Varela, 1990; Villa-Martínez, et al. 2003).

Chile central comenzó a ser habitado durante el Pleistoceno Tardío, y se han definido varios períodos temporales y tradiciones culturales para la subsiguiente prehistoria humana de una parte de la zona central (Falabella, et al. 2016; Núñez, et al. 2016; Uribe y Sánchez , 2016). Los restos óseos humanos objeto de esta investigación se relacionan con las poblaciones del Holoceno tardío desde el Período Alfarero Temprano hasta el Período Tardío (ca. 300 aC - 1536 dC), de quienes habitaron lo que hoy conocemos como la región de Valparaíso.

1.1 Período Alfarero Temprano (ca. 300 aC- 1000/1100 dC.)

La presencia de cerámica en el registro arqueológico indica el inicio del Período Alfarero Temprano (PAT), sin embargo la introducción de esta nueva tecnología no significa necesariamente un cambio simultáneo en la vida de los cazadores-recolectores. De hecho, este período se caracteriza por pequeños y heterogéneos grupos de personas que coexisten en una misma área geográfica, manteniendo diferentes prácticas de subsistencia, cultura material, prácticas funerarias y patrones de asentamiento. Además, algunos grupos del alfarero temprano mantuvieron un estilo de vida cazador-recolector, con pocos cambios en las estrategias de subsistencia durante gran parte de este período, mientras que otros grupos pasaron a una agricultura incipiente con presencia de cultígenos como la quínoa (*Chenopodium quinoa*) y el maíz (*Zea mays*) que hacen inferir sobre el inicio de campos de cultivo a pequeña escala (Ávalos, 2005; Ávalos y Saunier, 2011; Falabella, et al. 2016; Planella y Tagle, 2004).

Para el Período Alfarero Temprano se han propuesto varios complejos culturales, de los cuales algunos eran diacrónicos y otros sincrónicos. En ese sentido, los complejos mejor definidos incluyen las Comunidades Alfareras Iniciales (ca. 300 aC - 200 dC), Bato (ca. 200 - 1000 dC) y Llolleo (ca. 200 - 1200 dC) (Falabella y Stehberg, 1989; Falabella, et al. 2015; Sanhueza Riquelme, 2016). Las Comunidades Alfareras Iniciales (CAI) dependían principalmente de recursos vegetales silvestres (C3), aunque también se ha registrado la presencia de quínoa en algunos sitios de las CAI (Quiroz y Belmar, 2004; Sanhueza y Falabella, 1999).

Los sitios asociados al complejo cultural Bato se localizan principalmente al oeste de la cordillera costa, concentrándose mayormente en la parte más septentrional de la costa de Chile central, particularmente alrededor de la desembocadura del río Aconcagua (Ávalos y Saunier, 2011). Sin embargo, en esta zona también se han registrado contextos Bato en algunos sitios del interior (Ávalos, 2007; Hermosilla, 1994). Los grupos Bato practicaron en gran medida un estilo de vida de cazadores-recolectores con cierto grado de movilidad territorial, con dependencia de la costa cercana y de alimentos marinos de bajos niveles tróficos, como también de camélidos silvestres y recursos de plantas silvestres (Ávalos y Saunier, 2011; Carmona, et al. 2001; Rivas y González, 2008). No obstante, la presencia de piedras de moler y restos arqueobotánicos de quínoa y maíz en algunos sitios, particularmente en los sitios de interior, también demuestra el uso incipiente o acceso de los grupos Bato a algunas de los primeras plantas domesticadas (Ávalos, 2005, Planella y Tagle, 2004).

Los grupos Llolleo coexistieron junto con los Bato, aunque se les considera más sedentarios y con una mayor preferencia hacia los cultígenos. Estos pequeños y autosuficientes grupos con una identidad colectiva Llolleo se establecieron en asentamientos dispersos en todo el curso medio y superior del Valle del Aconcagua, la Cuenca de Santiago, la Cuenca de Rancagua y también en algunos sitios costeros, principalmente alrededor de la desembocadura del río Maipo (Falabella, et al. 2016). En los sitios Llolleo de la cuenca Maipo-Mapocho (Planella y Tagle, 2004) se ha registrado una mezcla de plantas silvestres y cultivadas, junto con huesos de guanaco (*Lama guanicoe*). Asimismo, el equipamiento de caza identificado en contextos Llolleo ha sido limitado, con menos puntas de proyectil que en los sitios Bato, lo que sugiere que la caza tuvo una menor importancia para los Llolleo que para sus contemporáneos Bato (Falabella, et al. 2016). Por otra parte, los cultígenos identificados en contextos Llolleo incluyen maíz, quínoa, porotos (*Phaseolus sp.*), zapallo (*Curcurbita sp.*) y calabaza (*Lagenaria sp.*) (Planella, et al. 2014; Planella y Tagle, 2004; Sanhueza, et al. 2003).

1.2 Período Intermedio Tardío (ca. 1000/1200 dC – 1450 dC)

La transición al Período Intermedio Tardío (PIT) provocó un considerable cambio cultural y tecnológico con los Aconcagua, reconocidos como el complejo cultural dominante en Chile central durante este período. Los asentamientos se localizaban generalmente a lo largo de las terrazas fluviales de ríos y valles y comprendían unas pocas unidades residenciales. Los campos de cultivo estaban situados adyacentes a las áreas habitacionales, en tanto los espacios para procesar alimentos, para la producción de materiales líticos y cerámicos también fueron designados. Si bien los Aconcagua habitaron preferentemente los valles interiores, durante el Periodo Intermedio Tardío también se han registrado algunos sitios en entornos costeros, como Las Brisas 10-14 (Westfall, 1999).

El desarrollo de una agricultura más intensa en algunos grupos de la zona central de Chile apareció ca. 1000 DC, pero para otros no tuvo lugar hasta alrededor del 1200 dC (Falabella, et al. 2016). Durante este periodo la mayor dependencia del maíz se demuestra por la ubicuidad del recurso en los sitios de la zona, por la presencia de una variedad más amplia de la especie, así como por un aumento en el tamaño de los granos del maíz (Belmar y Quiroz, 2003; Planella, et al. 2014 en Falabella, et al. 2016). Además el aumento en el tamaño y variedad de porotos, y el tamaño del grano

de la quínoa proporcionan evidencia adicional sobre la intensificación de la agricultura durante este período (Planella, et al. 2015). También hay indicios de una mayor dependencia de la carne de guanaco, lo que sugiere que los camélidos pudieron haber sido domesticados parcialmente, los cuales habrían sido alimentados con maíz para animarlos a permanecer cerca de las áreas de asentamiento (Becker, 1994; Sanhueza y Falabella, 2010; Tykot, et al. 2009).

1.3 Período Tardío (ca. 1450 dC - 1536 dC)

La presencia Inka en Chile central se estableció por el siglo XV. Conservadoramente, se acepta ca. 1450 dC (Uribe y Sánchez, 2016), aunque existen algunas fechados por termoluminiscencia de cerámica que sugieren una posible presencia anterior, antes del 1400 dC (Sánchez, 2003). La red vial Inka ha sido registrada longitudinalmente a través de Chile central hacia el sur, pasando al este a través de la cordillera de los Andes hacia Mendoza en Argentina. A su vez, las estructuras imperiales fueron utilizadas para fines ceremoniales, defensivos y administrativos, estableciéndose en puntos estratégicos a lo largo de los valles fluviales y caminos longitudinales (Coros y Coros, 1999), integrando el área de la frontera sur a su imperio.

Las culturas locales existentes, como Aconcagua y Diaguita, persistieron hasta el Período Tardío (PT), pero fueron parcialmente aculturadas, exhibiendo signos de influencia Inka en su cultura material. Junto con esto, se implementó una jerarquía más definida con unidades sociales encabezadas por caciques locales, donde las comunidades previamente dispersas se organizaron en pequeños asentamientos. Además, se incrementaron varias formas de producción, entre ellas la minería, la intensificación de la agricultura de maíz y la domesticación de camélidos (Uribe y Sánchez, 2016).

1.4 Análisis de Isótopos Estables

Los análisis de isótopos estables de carbono (δ13C) y nitrógeno (δ15N) han sido utlizados cada vez más en contextos arqueológicos para reconstruir la dieta e inferir acerca de las estrategias de subsistencia prehispánicas. Ahora, las diferencias en las proporciones de isótopos de carbono y nitrógeno pueden ser útiles para distinguir entre dietas dependientes de diferentes tipos de recursos vegetales, así como entre ecosistemas marinos, terrestres y a veces de agua dulce (Schoeninger y DeNiro, 1984). Las relaciones de isótopos estables de carbono se calculan en relación con un estándar internacional, el carbonato de Pee Dee Belemnite (PDB), que es rico en 13C, lo que significa que los valores de δ13C medidos desde la mayoría de las plantas y animales son negativos cuando se expresan respecto al estándar. Por otro lado, las relaciones de isótopos estables de nitrógeno se miden y expresan respecto al nitrógeno atmosférico (AIR).

Los valores isotópicos estables de colágeno óseo representan un promedio más amplio de la dieta, aproximadamente de la última década de vida los individuos. Sin embargo, la tasa de remodelación ósea puede variar algo dependiendo de factores como la edad, el estado nutricional y el hueso particular que se ha muestreado para el análisis (Tieszen, et al. 1983; Hedges, et al. 2007). Otro aspecto a considerar es que el δ13C de colágeno óseo está sesgado para la porción proteica de la dieta (Ambrose y Norr, 1993; Tieszen y Fagre, 1993), y para δ15N representa sólo el componente proteico de la dieta, es decir, la contribución dietética de las porciones de lípidos y carbohidratos de los alimentos estará subrepresentada en los datos de colágeno óseo.

A través de los isótopos estables de carbono también se pueden distinguir entre algunos tipos de recursos terrestres basados en diversas vías fotosintéticas usadas por las plantas (tales como C3 o C4). Para el ambiente de Chile central, el análisis de isótopos estables de carbono puede ser particularmente útil para detectar la introducción e intensificación del maíz (un recurso C4) en las dietas humanas prehispánicas, considerando que la vegetación en zonas templadas generalmente sigue una vía fotosintética C3, al igual que gran parte de la vegetación nativa de Chile central. Ciertos cultígenos y cereales importantes, incluido el maíz, siguen la vía fotosintética C4. Los valores de los isótopos estables de carbono para la vegetación C3 generalmente son alrededor de -26,5 ‰, mientras que los C4 tienen valores alrededor de -12,5 ‰ (Smith y Epstein, 1971). Las plantas modernas requieren una corrección de ca. +1,5 ‰ en comparación con el material arqueológico debido al Efecto Suess; correspondiente a un agotamiento en las proporciones isotópicas de carbono atmosférico como resultado de la mezcla con dióxido de carbono industrial producido por la incineracion de combustibles fósiles (Keeling, 1979).

Cabe destacar que debido a los procesos metabólicos, hay una compensación entre los valores isotópicos de las plantas y los tejidos corporales de los animales que los consumen. Por ejemplo, los mamíferos tienen un desplazamiento de alrededor de +5 ‰ de los valores de δ13C del recurso a los valores de δ13C observados en el colágeno óseo del consumidor (Δ13Cdiet-collagen) (Ambrose y Norr, 1993; Tieszen y Fagre, 1993). Es decir, esto incluye un cambio de nivel trófico de ca. +1 ‰ para los isótopos de carbono, lo mismo ocurre en cada paso posterior de la cadena alimentaria (Boche-

rens y Drucker, 2003).

Los datos isotópicos publicados anteriormente para varias especies de plantas en Chile central (ver Tabla 1) pueden proporcionar una guía sobre los puntos extremos δ13C que podrían esperarse para los consumidores de plantas C3 o C4 en esta zona. Ahora, basándose en el valor promedio de plantas C3 silvestres y cultivadas de Chile central a 26,6 ‰, los herbívoros que consumen una dieta exclusivamente C3 tendrían teóricamente valores de colágeno óseo δ13C alrededor de -20,1 ‰ (cuando se toma en cuenta el desplazamiento de +5 ‰ Δ13Cdieta-colageno, y añadiendo un +1,5 ‰ adicional para tener en cuenta el Efecto Suess). Si los seres humanos tuvieran una dieta basada en herbívoros que consumen pasto C3, como Lama guanicoe, su puntaje estimado de δ13C sería alrededor de -19,1 ‰, es decir, el rango estimado δ13C de colágeno óseo para una dieta C4 pura sería alrededor de -4,7 ‰. Sin embargo, es improbable que la gente obtenga el 100% de su proteína dietética de los recursos C4, incluso en comunidades fuertemente dependientes del maíz. Por ejemplo, varios estudios en América Central y del Sur han reportado valores promedio de δ13C alrededor de -12,1 a -9,2 ‰ para agricultores de maíz (Finucane, et al. 2006; Williams, 2005; Reed, 1994; Williams, et al. 2017).

Recurso	Contexto	*n*	Media $\delta^{13}C \pm 1$ SD (‰)	Min. – Max.
Alga Marina	Moderno	2	-15,7 ± 2,3	-17,3 a -14,0
C_3 Vegetación Silvestre	Moderno	14	-26,6 ± 2,9	-30,5 a -21,0
C_3 Cultígeno	Moderno	6	-26,6 ±1,6	-29,3 a -24,7
C_4 Cultígeno	Moderno	1	-11,2	

Tabla 1: Resumen valores de isótopos estables de carbono para muestras de flora modernas de Chile central, adaptado de Falabella et al. (2007).

Los seres humanos que consumen una dieta con una mezcla de recursos terrestres tendrán valores de δ13C intermedios a los rangos de una dieta C3 y C4. Sin embargo, los valores de isótopos estables de carbono de las plantas marinas también se encuentran entre estos rangos, por lo que potencialmente se superponen con los valores esperados de una dieta terrestre mixta. Esto puede complicar los esfuerzos para distinguir una dieta marina de una dieta C3-C4 terrestre al interpretar sólo los resultados de δ13C.

Los isótopos estables de nitrógeno también proporcionan información sobre el nivel trófico, con un aumento de aproximadamente de 3-5 ‰ en cada paso de la cadena alimentaria (Schoeninger y DeNiro, 1984). Dado que hay muchos otros niveles tróficos en la cadena alimentaria marina, en comparación con las cadenas alimentarias terrestres, los consumidores de recursos marinos pueden distinguirse por mayores valores de δ15N. Por ejemplo, los agricultores europeos prehistóricos con dietas que consisten en plantas y animales terrestres tienen valores de colágeno δ15N alrededor de 8-11 ‰, con una dieta mixta de proteínas terrestres y marinas dará como resultado valores intermedios δ15N alrededor de 11-15 ‰; y los cazadores marinos que consumen recursos de alto nivel trófico tendrán valores aún mayores de δ15N, a menudo alrededor de 15-20 ‰ (Schoeninger y DeNiro, 1983; Schulting, En prensa). De igual manera las poblaciones de la costa del norte de Chile, que se sabe que dependen en gran medida de alimentos marinos de alto nivel trófico, han sido reportadas con δ15N tan alto entre 17,3 a 26,7 ‰ (Roberts, et al. 2013).

Existen otros factores que también pueden elevar δ15N en los recursos alimenticios, además del cambio de nivel trófico, son la aridez (Pate y Anson, 2008) y el abono de los cultivos (Bogaard, et al. 2007, Szpak, et al. 2012; Bogaard, et al. 2013; Fraser, et al. 2011). Por el contrario, las plantas fijadoras de nitrógeno, en las que se incluyen la mayoría de las leguminosas, han reducido el δ15N en comparación con las plantas no leguminosas debido a su capacidad para fijar nitrógeno directamente de la atmósfera (Handley y Raven, 1992). Por lo tanto, los seres humanos que consumieron una dieta con leguminosas también habrían reducido relativamente el δ15N. De hecho, el consumo de leguminosas ha sido sugerido como explicación de los bajos valores de δ15N de colágeno óseo humano en sitios del Neolítico medio en Francia (Schulting y Hamilton, 2012).

Tambien se dispone de datos isotópicos de referencia para diversos recursos faunísticos arqueológicos y modernos de Chile central (Falabella, et al. 2007) los que proporcionan un antecedente útil para este estudio (ver Tabla 2).

Estas muestras fueron obtenidas de Chile central, de los cuales se incorporaron algunos datos de esa área de estudio para esta investigación.

Investigaciones isotópicas previas de sitios arqueologicos ubicados al sur de Chile central, cercanos a los ríos Maipo, Mapocho y Cachapoal en Santiago y Rancagua ofrecen datos de colágeno óseo humano para cerca de 82 individuos (Falabella, et al. 2007; Sanhueza y Falabella, 2010, Tykot, et al. 2009). Estos incluyen poblaciones de sitios costeros, valles interiores y cordillera andina; y abarcan períodos temporales y culturales desde el Arcaico hasta el Tardío.

Recurso Faunístico	Contexto	Material	*n*	Media $\delta^{13}C$ ± 1SD (‰)	Min. – Max.	Media $\delta^{15}N$ ± 1SD (‰)	Min. – Max.
Herbivoros Terrestres	Arqueológico	Hueso	6	-19,5 ± 0,6	-20,2 a -18,6	5,0 ± 0,9	4,0 a 6,4
Lacustre (Interior)	Arqueológico	Hueso	1	-16,0		2,1	
Lacustre (Costa)	Arqueológico	Hueso	2	-22,9 ± 0,8	-23,4 a -22,3	7,1 ± 2,6	5,2 a 8,9
Mamífero Marino	Arqueológico	Hueso	1	-11,7		20,2	
Pez Marino	Arqueológico	Hueso	1	-14,9		12,7	
Pez Marino	Moderno	Hueso	4	-13,5 ± 1.7	-15,5 a -11,4	17,7 ± 1,1	16,0 a 18,5
Molusco Marino	Moderno	Carne	4	-15,3 ± 1.7	-17,2 a -13,2	16,0 ± 1,5	14,2 a 17,6

Tabla 2: Resumen de valores de isótopos estables de carbono y nitrógeno para la fauna de Chile central, adaptado de Falabella et al. (2007).

La limitada evidencia sobre las dietas durante el Arcaico para esta zona indica que los cazadores-recolectores de este período dependían de un ecosistema C3 (Sanhueza y Falabella, 2010). Una tendencia similar se observó en las Comunidades Alfareras Iniciales del Período Alfarero Temprano en Chile central, donde la evidencia isotópica del período Alfarero Temprano después del 200 dC aproximadamente, demuestra la práctica contemporánea de por lo menos dos estrategias de subsistencia terrestre diferentes en los sitios del interior, ligadas a menudo a los complejos culturales contemporáneos Bato y Llolleo descritos para esta zona. Los análisis isotópicos de los sitios que rodean los ríos Maipo, Mapocho y Cachapoal demostraron que Llolleo tuvo alguna aportación de cultígenos C4, mientras que Bato reveló resultados más variables, que sugieren una dependencia moderada de recursos marinos para algunos, mientras que otros consumieron una dieta terrestre C3 (Falabella, et al. 2007; Sanhueza y Falabella, 2010).

Los resultados isotópicos previos del Período Intermedio Tardío mostraron enriquecimiento significativo de δ13C en colágeno de hueso humano, lo que indica que el cultígeno dominante de elección fue el maíz (Falabella, et al. 2007). Así, el maíz siguió apareciendo en la dieta de los grupos del Periodo Tardío, aunque se redujo en proporción (valores más negativos de δ13C) y se mezcló con un mayor aporte de recursos C3 en comparación con el Período Intermedio Tardío (Falabella, et al. 2007).

2 MATERIALES Y MÉTODOS

2.1 Muestras

Se seleccionaron muestras de hueso humano de 24 individuos de la colección bioantropológica del Museo de Historia Natural de Valparaíso (Tabla 3). Todos los restos óseos se encontraban altamente fragmentados. Con el fin de minimizar el daño a la colección, para los análisis de isótopos estables sólo se seleccionaron muestras de material ya fragmentado. El material muestreado pro viene de varios sitios de la región de Valparaíso de Chile central. Los sitios incluyen el Periodo Alfarero Temprano (n = 19), el Intermedio Tardío (n = 3) y el Periodo Tardío (n = 2), los cuales provienen tanto de la costa (n = 12) como del valle interior (n = 12). Los sitios costeros se definen como aquellos situados a lo largo de la llanura costera y al oeste de la cordillera de la costa, mientras que los sitios de interior corresponden a los ubicados al este de la cordillera de la costa o más adentro del valle interior, y existe una distancia de aproximadamente 17 km desde la costa hasta el sitio interior más cercano incluido en este estudio (Villa Alemana). Cabe señalar que la información contextual disponible para las colecciones esqueléticas humanas es variable y, en algunos casos limitada, correspondiente sólo a la etiqueta de almacenamiento del museo.

2.2 Métodos

Cuando fue posible, se determinó sexo mediante la evaluación morfológica de los fragmentos de pélvis y de cráneo (Buikstra y Ubelaker, 1994). La edad se estimó en base a la erupción dental para subadultos (Al-Qahtani, et al. 2010) y a través de desgaste dental para adultos (Lovejoy, 1985).

Los análisis isotópicos estables de carbono y nitrógeno se realizaron en el Laboratorio de Investigación de Arqueología e Historia del Arte de la Universidad de Oxford. Primero, el colágeno se extrajo de las muestras de hueso utilizando un protocolo modificado de Longin (1971) y los fragmentos óseos se limpiaron mediante granallado con óxido de aluminio. Una vez listas, las submuestras fueron trituradas y desmineralizadas en HCl 0,5 M a 5 ° C durante varios días y la solución de HCl se cambió periódicamente hasta que las muestras dejaron de producir CO2 observable en reacción al ácido. Luego, las muestras desmineralizadas se colocaron en tubos sellados de pH 3 H2O y se gelatinizaron a 70ºC durante 48 horas. Finalmente, el sobrenadante se filtró para eliminar el residuo insoluble utilizando 45-90 µm Ezee-filtersTM y luego se liofilizó durante aproximadamente 48 horas.

Muestra	Sitio	Individuo*	Período (Cultura)	Entorno	Sexo	Edad	Elemento
16039	Las Brisas 3	1	PAT (Bato)	Costa	Indet.	Subadulto (~11.5 años)	Radio
16040	Las Brisas 10-14	1	PIT (Aconcagua)	Costa	F?	Adulto (35-40)	Fémur
16041	Las Brisas 10-14	2	PIT (Aconcagua)	Costa	F	Adulto (45-55)	Costilla
16042	Las Brisas 10-14	3	PIT (Aconcagua)	Costa	F	Adulto (45-55)	Tibia
16043	Concon, Camino Internacional+	1	PAT (Bato)	Costa	M	Adulto (45-55)	Fíbula
16044	Concon, Camino Internacional+	"Individuo removido"	PAT (Bato)	Costa	Indet.	Adulto (40-50)	Cráneo
16045	Concon, Camino Internacional+	2	PAT (Bato)	Costa	F?	Adulto (45-55)	Costilla
16046	Papudo	nd	PAT#	Costa	F	Adulto (16-20)	Fémur
16047	Papudo	nd	PAT#	Costa	F?	Adulto	Cráneo
16048	Papudo	nd	PAT#	Costa	F	Adulto	Cráneo
16049	Calle Ricardo, Santa Cruz	Enterratorio 2653	PAT (Llolleo)#	Interior	M	Adulto	Fíbula
16050	Calle Ricardo, Santa Cruz	Enterratorio 2654	PAT (Llolleo)#	Interior	Indet.	Adulto (45-55)	Fémur
16051	Calle Ricardo, Santa Cruz	Enterratorio 2655	PAT (Llolleo)#	Interior	Indet.	Adulto	Fémur
16052	Calle Ricardo, Santa Cruz	Enteratorio 2655	PAT (Llolleo)#	Interior	M?	Adulto	Cráneo
16053	Calle Ricardo, Santa Cruz	Enteratorio 2656	PAT (Llolleo)#	Interior	M?	Adulto	Cráneo
16054	Calle Ricardo, Santa Cruz	Enteratorio 2657	PAT (Llolleo)#	Interior	Indet.	Adulto	Fémur
16055	Calle Ricardo, Santa Cruz	Enteratorio 2658	PAT (Llolleo)#	Interior	Indet.	Adulto	Fémur
16056	S-Bato 1	"Disturbado"	PAT (Bato)	Costa	Indet.	Adulto	Fémur
16057	S-Bato 1	1	PAT (Bato)	Costa	M?	Adulto (35-50)	Costilla
16058	Villa Alemana	1	PT (Aconcagua-Inka)	Interior	Indet.	Subadulto (16.5-19.5)	Tibia
16059	Villa Alemana	2	PT (Aconcagua-Inka)	Interior	Indet.	Adulto	Cráneo
16060	Las Chilcas	"Hallazgo 10"	PAT (Bato)	Interior	M	Adulto (45-55)	Cráneo
16061	Pocochay	1	PAT (Llolleo)#	Interior	M	Adulto (45-55)	Radio
16062	Pocochay	2	PAT (Llolleo)#	Interior	M?	Adulto (24-30)	Cráneo

Tabla 3: Detalle de las muestras de hueso humano de la colección bioantropológica del Museo de Historia Natural de Valparaíso. * Los números/nombres aquí registrados son según las etiquetas asociadas a los restos. # Se han realizado atribuciones culturales y temporales para estas muestras basadas únicamente en las etiquetas del museo. + Estas muestras pueden referirse a dos sitios, Concon 11 o Camino Internacional, ubicados a 150m de distancia. Sin embargo, los restos están almacenados juntos sin ningún registro de cuál provenía de Concon 11 y cuál de Camino Internacional.

El colágeno se analizó usando un Espectrómetro de Masa de Relación Isotópica Sercon 20/22 en modo de flujo continuo. Todas las muestras se analizaron por duplicado para asegurar la reproducibilidad, con una precisión mayor que δ0,2 ‰. Se incluyeron normas internas del valor de alanina conocido a lo largo de las pruebas para permitir la corrección de la deriva. También se incluyeron estándares internos de colágeno de vaca y foca para la calibración de dos puntos de los resultados (Coplen, et al. 2006). Los valores isotópicos promediados se expresan en unidad por mil (‰) con respecto a los estándares internacionales para δ13C (VPDB) y δ15N (AIR).

Se utilizó IBM SPSS Statistics para Macintosh, versión 22.0 para todos los análisis estadísticos. Los datos se analizaron para verificar su normalidad usando las pruebas de Shapiro-Wilk, que determinaron el subsecuente uso de las pruebas paramétricas (prueba-t de Student) o no paramétricas (Mann-Whitney U) al comparar dos grupos. Además se emplearon pruebas de bilateridad, con δ = 0,05.

Todas excepto una de las 24 muestras cumplieron criterios de calidad de colágeno aceptados, con rendimientos > 1% y C:N entre 2,9 y 3,6 (Tabla 4) (DeNiro, 1985; van Klinken, 1999), sólo una muestra de Villa Alemana (16058) poseía un valor inaceptablemente alto de 3,86, la cual se ha excluido del análisis posterior.

3 RESULTADOS Y DISCUSIÓN

Los resultados se muestran en la tabla 4 y en la figura 2, y se presentan por clasificación geográfica y temporal, junto con datos comparativos de las zonas de Santiago y Rancagua en la tabla 5. Existen diferencias significativas tanto para los valores δ13C como δ15N para los sitios costeros en comparación con los sitios de interior (p = 0,006 para δ13C, p = 0,001 para δ15N, test de Mann-Whitney U). Además, el rango de valores de δ15N de sitios costeros de Chile central (5,4 ‰ a 14,8 ‰, media 10,5 δ 1,9 ‰) es mucho menos elevado en comparación con los valores de δ15N de poblaciones altamente dependientes de recursos marinos de la región hiperárida del Norte Grande de Chile (ver Fig. 3) (Petruzzelli, et al. 2012; Roberts, et al. 2013; Santana-Sagredo, et al. 2016; Santana-Sagredo, et al. 2015). No obstante, los valores de δ15N y δ13C de este estudio sugieren que la dieta costera local incluyó una mezcla de recursos terrestres complementados con recursos marinos, particularmente aquellos de niveles tróficos inferiores tales como moluscos o algas marinas. Estos resultados son consistentes con la presencia de conchales arqueológicos registrados a lo largo de la costa (Carmona, et al. 2001; Seelenfreund y Westfall, 2000). En investigaciones isotópicas anteriores se observaron diferencias similares entre los grupos costeros e interiores de la zona central de Chile y, para el Período Alfarero Temprano, se interpretaron como evidencia de asentamientos en zonas ecológicas definidas, en lugar de un modelo de migración regular entre costa e interior (Falabella, et al. 2007).

Los valores de δ15N para los individuos de interior son bastante bajos. El valor promedio del colágeno de hueso humano para δ15N (5,9 δ 2,0 ‰) es similar a los medidos para herbívoros terrestres de la región (Lama guanicoe, media δ15N 5,0 δ 0,9 ‰) (Falabella, et al. 2007), en lugar de los +3.0 a 5.0% más altos que se esperaría si los seres humanos consumían regularmente carne de guanaco. Los bajos valores de δ15N observados en humanos pueden deberse a una ingesta insignificante de proteínas animales entre las poblaciones del interior, aunque esto iría en contra de la evidencia de los sitios arqueológicos, que incluyen restos de camélidos e instrumentos de caza (Falabella, et al. 2016; Ávalos y Saunier, 2011). Ahora, teniendo en cuenta la disponibilidad variada de porotos (Phaseolous spp.) y maní (Arachis hypogaea) en el centro de Chile (Pardo y Pizarro, 2013, Planella y Tagle, 2004), otra explicación plausible podría ser que las leguminosas fijadoras de nitrógeno que aparecen regularmente en la dieta local estén reduciendo los valores de colágeno óseo de δ15N en los consumidores.

Ahora bien, los resultados del material analizado tienen un amplio rango de δ13C (-20,4 ‰ a -11,4 ‰) que demuestra la variabilidad en las estrategias de subsistencia a lo largo del tiempo, con dietas que van desde una alta dependencia de C3 hasta una sustancial contribución de alimentos C4. Con base en las estimaciones anteriores de los rangos dietéticos para esta región (-20,1 ± 2,9 para una dieta 100% C3 y aproximadamente -4,7 ‰ para una dieta 100% C4), se puede estimar que el rango de valores de δ13C de este estudio incluyen dietas que van desde una dependencia de 100% de C3 en el Período de Alfarero Temprano (como las de Pocochay, donde δ13C = -20,4 ‰) hasta una contribución de aproximadamente 57% de los recursos de C4 a la porción de proteína de la dieta de la muestra del Período Tardío de Villa Alemana (δ13C = -11,4 ‰).

Se observa un marcado incremento en los valores de δ13C de las muestras del Período Alfarero Temprano al Período Intermedio Tardío y nuevamente al Período Tardío, lo que indica la creciente inclusión del maíz a través de períodos temporales sucesivos. Asimismo, se han registrado diferencias similares entre los grupos de la cuenca de Santiago y de Rancagua, lo que apoya la idea que las prácticas dietéticas son una característica definitoria entre diferentes grupos culturales en la prehistoria de la zona central (Falabella, et al. 2007).

Muestra	Sitio	Período (Cultura)	Entorno	Sexo	$\delta^{13}C$ (‰VPDB)	$\delta^{15}N$ (‰ AIR)	% Rendimiento	C:N	%N	%C
16039	Las Brisas 3	PAT (Bato)	Costa	Indet.	-17,9	11,7	7,6	3,25	15,7	43,7
16040	Las Brisas 10-14	PIT (Aconcagua)	Costa	F?	-13,5	5,4	7,6	3,23	13,3	36,8
16041	Las Brisas 10-14	PIT(Aconcagua)	Costa	F	-13,1	10,0	17,5	3,24	15,4	42,7
16042	Las Brisas 10-14	PIT (Aconcagua)	Costa	F	-13,5	9,4	4,5	3,31	12,6	35,7
16043	Concon, Camino Internacional	PAT (Bato)	Costa	M	-15,8	10,0	8,7	3,26	15,6	43,5
16044	Concon, Camino Internacional	PAT (Bato)	Costa	Indet.	-15,4	8,9	7,0	3,25	15,3	42,7
16045	Concon, Camino Internacional	PAT (Bato)	Costa	F?	-15,4	9,3	4,7	3,24	14,0	38,9
16046	Papudo	PAT	Costa	F	-16,9	9,8	5,4	3,25	15,1	42,2
16047	Papudo	PAT	Costa	F?	-16,3	14,5	4,4	3,21	15,4	42,3
16048	Papudo	PAT	Costa	F	-18,7	10,9	13,5	3,21	15,6	43,0
16049	Calle Ricardo, Santa Cruz	PAT (Llolleo)	Interior	M	-14,7	5,8	7,1	3,24	8,9	24,8
16050	Calle Ricardo, Santa Cruz	PAT (Llolleo)	Interior	Indet.	-19,3	5,0	3,5	3,21	12,6	34,7
16051	Calle Ricardo, Santa Cruz	PAT (Llolleo)	Interior	Indet.	-18,6	5,9	2,0	3,28	12,9	36,1
16052	Calle Ricardo, Santa Cruz	PAT (Llolleo)	Interior	M?	-19,5	4,0	1,8	3,58	3,3	10,2
16053	Calle Ricardo, Santa Cruz	PAT (Llolleo)	Interior	M?	-19,5	5,0	3,2	3,29	12,4	35,0
16054	Calle Ricardo, Santa Cruz	PAT (Llolleo)	Interior	Indet.	-19,1	5,2	5,4	3,24	11,6	32,3
16055	Calle Ricardo, Santa Cruz	PAT (Llolleo)	Interior	Indet.	-19,4	4,3	2,8	3,38	8,7	25,1
16056	S-Bato 1	PAT (Bato)	Costa	Indet.	-18,2	10,9	4,9	3,35	13,8	39,5
16057	S-Bato 1	PAT (Bato)	Costa	M?	-14,6	14,8	9,9	3,31	13,4	38,1
16058	Villa Alemana	PT (Aconcagua-Inka)	Interior	Indet.	*-16,0*	*4,2*	*1,4*	*3,86**	*1,6*	*5,2*
16059	Villa Alemana	PT (Aconcagua-Inka)	Interior	Indet.	-11,4	11,4	4,3	3,38	13,0	37,7
16060	Las Chilcas	PAT (Bato)	Interior	M	-19,0	7,6	2,7	3,33	9,4	26,9
16061	Pocochay	PAT (Llolleo)	Interior	M	-20,4	5,4	3,6	3,26	15,1	42,1
16062	Pocochay	PAT (Llolleo)	Interior	M?	-20,4	5,7	6,5	3,28	16,0	45,0

Tabla 4: Resultados de las muestras de carbono (δ13C) y nitrógeno (δ15N) estable de colágeno de hueso humano. * Se registra en cursiva la muestra con criterios de calidad de colágeno inaceptables.

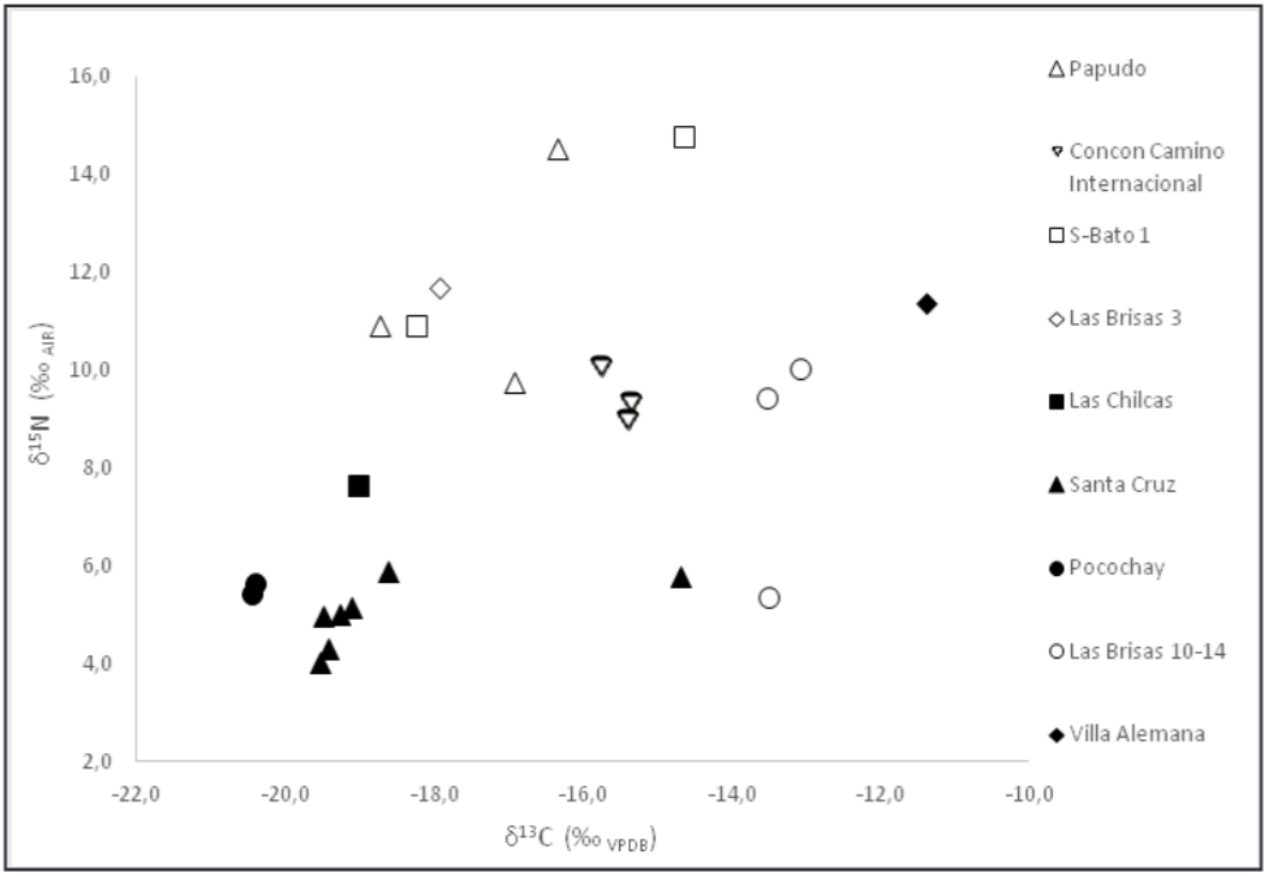


Figura 2: Resultados de carbono (δ13C) y nitrógeno (δ15N) estable de las muestras de colágeno de hueso humano representadas por sitio. Los símbolos vacíos representan los sitios costeros y los símbolos sólidos representan los entornos de interior.

Setting	Período Temporal	*n*	Media $\delta^{13}C$ ±1SD (‰)	Min. – Max.	Media $\delta^{15}N$ ±1SD (‰)	Min. – Max.
Este Estudio						
Costa	Periodo Alfarero Temprano	9	-16.6 + 1.4	-18.7 a -14.6	11.2 + 2.1	8.9 a 14.8
	Período Intermedio Tardío	3	-13.4 ± 0.2	-13.5 a -13.1	8.3 ± 2.5	5.4 a 10.0
Interior	Periodo Alfarero Temprano	10	-19.0 + 1.6	-20.4 a -14.7	5.4 + 1.0	4.0 a 7.6
	Período Tardío	1	-11.4		11.4	
*Estudios Previos**						
Costa	Arcaico	4	-18.7 + 1.1	-19.8 a -17.6	10.2 + 2.7	7.0 a 13.1
	Alfarero Temprano (Bato)	9	-18.0 ± 1.0	-19.9 a -16.6	9.8 ± 1.6	8.2 a 11.7
	Alfarero Temprano (Llolleo)	8	-15.0 + 0.9	-16.2 a -13.5	10.6 + 1.6	7.7 a 12.6
	Período Intermedio Tardío	8	-13.4 ± 1.9	-17.3 a -10.7	10.1 ± 2.2	8.1 a 14.3
Interior	Arcaico	4	-18.7 + 0.6	-19.2 a -17.9	8.8 + 3.9	3.9 a 7.6
	Alfarero Temprano (Comunidades Alfareras Iniciales)	6	-20.1 + 0.3	-20.3 a -19.6	4.5 + 0.7	3.8 a 5.5
	Alfarero Temprano (Bato)	2	-18.4 ± 1.9	-19.7 a -17.0	6.1 ± 0.4	5.8 a 6.3
	Alfarero Temprano (Llolleo)	12	-14.1 ± 1.5	-17.6 a -12.7	5.8 ± 0.8	4.9 a 7.5
	Período Intermedio Tardío	18	-11.6 ± 0.8	-12.8 a -10.3	6.7 ± 1.0	5.0 a 8.1
	Período Tardío	15	-13.1 ± 1.2	-15.3 a -10.5	5.9 ± 1.0	4.4 a 8.5

Tabla 5: Valores de carbono (δ13C) y nitrógeno (δ15N) estable para los períodos temporales y entorno geográfico de las muestras de colágeno óseo humano de la Región de Valparaíso. * Los valores isotópicos promediados de estudios anteriores adaptados de Falabella et al. (2007); Falabella et al. (2008); Sanhueza y Falabella (2010); Tykot et al. (2009).

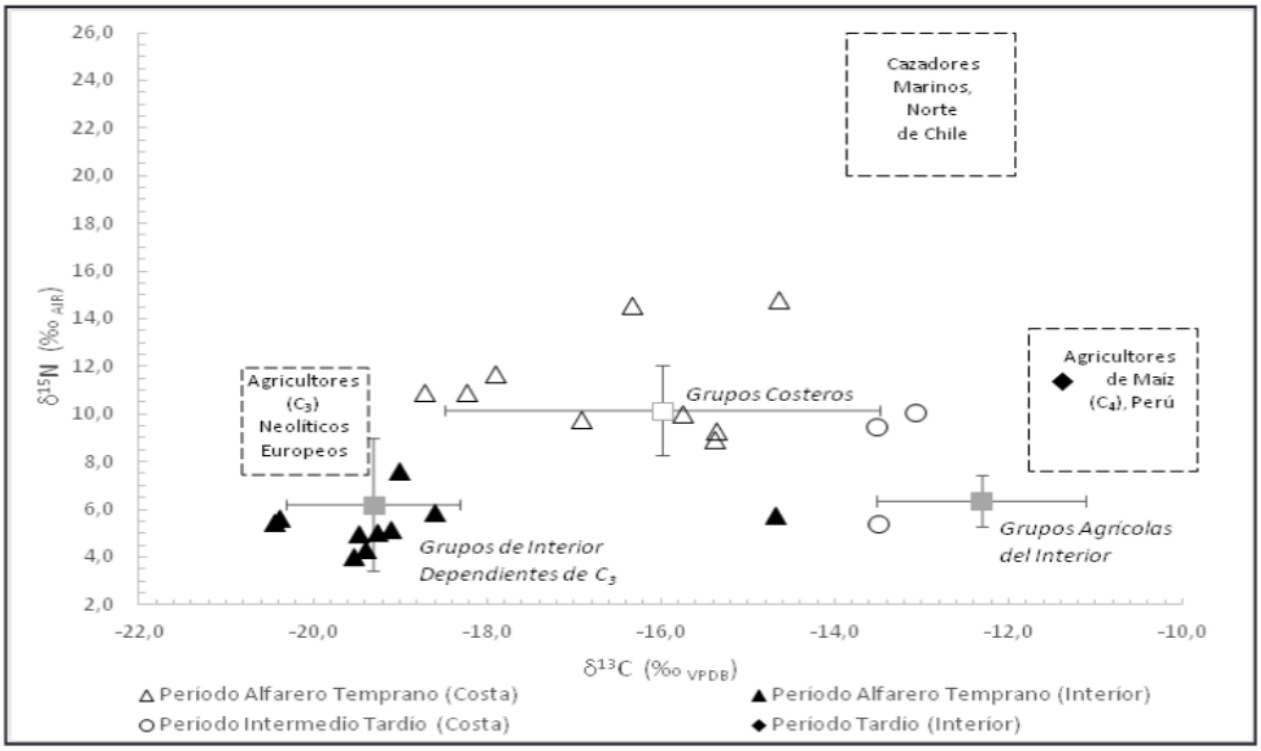


Figura 3: Resultados de carbono (δ13C) y nitrógeno (δ15N) estable de las muestras de colágeno de hueso humano de la Región de Valparaíso representadas por período temporal, acompañadas de ejemplos de dietas humanas en extremos del espectro δ13C y δ15N (C3, C4 , y marinas de alto nivel trófico) y datos comparativos de amplios grupos dietéticos identificados en las zonas vecinas de Santiago y Rancagua. Los valores medios δ 1SD se han calculado para estos grupos a partir de datos publicados previamente para el centro de Chile, combinando los sitios de los periodos del Arcaico y del Alfarero Temprano (Comunidades Alfareras Iniciales y Bato) para representar "grupos de interior dependientes de C3" para los "grupos costeros", y los datos combinados de los sitios interiores del Periodo Intermedio Tardío y del Período Tardío para representar "grupos agrícolas del interior" (después de Falabella, et al. 2007; Falabella, et al. 2008, Tykot et al ., 2009). Finalmente, los valores dietéticos comparados de agricultores europeos adaptados de Schulting (2015), cazadores marinos del norte de Chile de Roberts et al. (2013) y agricultores de maíz de Williams (2005) y Finucane et al. (2006).

3.1 Periodo Alfarero Temprano

No existen diferencias significativas entre los valores isotópicos de las muestras del Período Alfarero Temprano del interior de este estudio en comparación con el Período Alfarero Temprano del interior (ICC, Bato y Llolleo combinados) de las zonas de Santiago y Rancagua (p = 0,154 para δ13C y p = 0,895 para δ15N, pruebas t de student). Todas excepto una muestra (16049), tienen relativamente bajos los valores δ13C y δ15N manifestando una estrategia de subsistencia dependiente de C3, quedando dentro o cerca del rango combinado de los consumidores de C3 identificados (Período Arcaico, Comunidades Alfareras Iniciales y Bato) en Santiago y Rancagua.

Los registros del museo indican que Pocochay y Calle Ricardo Santa Cruz se atribuyen a la tradición Llolleo.

Pero cuando se comparan con los individuos Llolleo del interior de Santiago y Rancagua, los resultados isotópicos de los grupos Llolleo del valle del Aconcagua (Pocochay, Calle Ricardo Santa Cruz) son significatimente diferentes para δ13C (p <0,00001, prueba de Mann - Whitney U), pero no δ15N (p = 0,290, prueba t de Student) (Falabella, et al. 2007). Llolleo de la zona de Santiago y Rancagua posee valores δ13C mucho más elevados como resultado de una dieta mixta de C3-C4 que coincide con el cultivo incipiente de maíz entre estos grupos. Sin embargo, hay un individuo entre las muestras de Calle Ricardo Santa Cruz (16049, δ13C = -14,6 ‰ y δ15N = 5.8 ‰) cuyos resultados isotópicos caen dentro del mismo rango de Llolleo de C3-C4 que se conoce más al sur.

Los resultados de Pocochay y Calle Ricardo Santa Cruz en el valle del Aconcagua pueden representar grupos Llolleo muy tempranos correspondientes a una etapa en el Período Alfarero Temprano cuando los cultígenos C4 aún no se explotaban significativamente, o alternativamente pueden representar una persistencia prolongada de estrategias de subsistencia de cazadores-recolectores y dependencia primaria de los recursos C3 en la región de Valparaíso en comparación con los grupos contemporáneos de Santiago y Rancagua. Sin más información contextual para los sitios de Pocochay y Calle Ricardo Santa Cruz, particularmente respecto a la duración de la ocupación de estos sitios y la edad de

los entierros, es difícil especular sobre la razón de la diferencia entre la dieta de bajo nivel trófico C3 para la mayoría de estos individuos en comparacion con otros trabajos isotópicos anteriores de sitios Llolleo.

A diferencia de otros sitios del período Alfarero Temprano del interior de la colección bioantropológica del MHNV, los entierros recuperados de Las Chilcas se han atribuido a las primeras etapas de la tradición Bato (Hermosilla, 1994). Un individuo de este sitio que fue incluido en este estudio (16060), evidentemente su dieta estaba basada en C3. Sin embargo, el δ15N (7,6 ‰) de este individuo es más elevado que los de otros sitios del Período de Alfarero Temprano en el interior (Pocochay y Calle Ricardo Santa Cruz). El δ15N levemente más elevado en este individuo puede reflejar la explotación regular de herbívoros salvajes; en los sitios Bato de Chile central es común registrar una mayor frecuencia de instrumentos de caza, particularmente puntas líticas, piedras de moler en sitios Llolleo, lo que sugiere que los Bato eran los cazadores más activos de estos dos grupos culturales (Falabella, et al. 2016). Asimismo, se registraron varias puntas de proyectil durante la excavación en Las Chilcas, junto con restos de semillas y plantas, así como la presencia de algunos moluscos marinos (Hermosilla, 1994).

Los resultados de las muestras costeras del Período Alfarero Temprano de este estudio se encuentran principalmente dentro de los mismos rangos δ13C y δ15N que los datos publicados para grupos costeros en Chile central (Falabella, et al. 2007). Sin embargo, se observa que, en promedio, estos valores de δ13C son intermedios respecto a los datos para Chile central en general cuando se examinan por afiliación cultural (Bato y Llolleo). Los sitios Concon, Camino Internacional, Las Brisas 3 y S-Bato 1 se han atribuido al complejo cultural de Bato (Carmona, et al. 2001; Seelenfreund y Westfall, 2000; Novoa, 1999; Hurtado, 2003), pero los resultados de δ13C para los sitios PAT costeros en este estudio son significativamente diferentes de los resultados publicados anteriormente para ambos Bato costero ($p = 0,027$, t de Student) y Llolleo costero ($p = 0,017$, t de Student).

A excepción del sitio Las Brisas 3, ubicado cerca de la desembocadura del río Maipo, los sitios costeros del Período Alfarero Temprano de este estudio se encuentran mucho más al norte, alrededor de los ríos Aconcagua y La Ligua. Se han registrado restos de plantas y semillas silvestres de C3 en fogones de sitios costeros del Periodo Alfarero Temprano alrededor de la desembocadura del Aconcagua, así como cantidades significativas de hueso de Lama guanicoe (Carmona, et al. 2001). Los conchales arqueológicos incluyen varias especies de moluscos marinos, peces, aves marinas y lobos marinos (Otaria flavescens) (Seelenfreund, 2006; Seelenfreund y Westfall, 2000; Carmona, et al. 2001). Ademas, la frecuencia relativa y la variedad de especies marinas en estos sitios sugieren que la recolección de moluscos y la pesca son importantes medios de subsistencia para estos grupos.

3.2 Periodo Intermedio Tardío

Las muestras del Período Intermedio Tardío están representadas por tres individuos del sitio costero de Las Brisas 10-14, asociado al complejo cultural Aconcagua. Los datos isotópicos publicados anteriormente para el Período Intermedio Tardío de la costa central de Chile incluyen seis individuos de este mismo sitio, y dos de sitios cercanos, en Tejas Verdes 5 y Santo Domingo 1 (Falabella, et al. 2007). En este estudio, los valores de δ13C y δ15N para los tres individuos costeros del Período Intermedio Tardío coinciden con los resultados anteriores para este período y entorno, y no muestran diferencias estadísticamente significativas (δ13C $p = 0,971$, δ15N $p = 0,279$, t de Student).

Los resultados de Las Brisas 10-14 revelan valores δ13C más elevados comparados con las muestras del Período Alfarero Temprano. Estos resultados son consistentes con la mayor dependencia del maíz como cultivo básico durante el Período Intermedio Tardío. A pesar de estar localizado en la costa, uno de los individuos de este sitio (16040), con menor valor δ15N, parece haber estado consumiendo una dieta en gran parte terrestre. Además, los valores isotópicos para este individuo (δ13C = -13,5; δ15N = 5,4) corresponden estrechamente a los de grupos agrícolas del interior de los ríos Maipo y Mapocho durante el Período Tardío (Falabella, et al. 2008). Una posible explicación para el bajo valor δ15N de este individuo es que pudo haber vivido previamente en el valle interior y haber consumido una dieta de esa zona, y sólo más recientemente habría llegado al entorno costero de Las Brisas, ubicado cerca de la desembocadura del río Maipo. Si el traslado de este individuo a la costa fue reciente, la dieta de la zona interior todavía se reflejaría en los valores isotópicos de su colágeno óseo, que se refieren a los últimos varios años de la vida.

Los otros dos individuos de Las Brisas 10-14 tienen niveles de δ15N más consistentes con otros sitios costeros de este estudio y con Chile central en general, indicativo de una dieta que incorpora algunos recursos marinos. Esta dieta estaría basada en el maíz y complementada por algunos alimentos marinos, lo cual se corresponde con el cambio conocido hacia una mayor dependencia del maíz durante este período, como tambien con la presencia de conchales que contienen

varias especies de moluscos registrados durante la excavación de este sitio (Hurtado, 1999, Seelenfreund, et al. 2000, Westfall, 1999).

3.3 Periodo Tardío

Sólo hubo una muestra del Período Tardío, del sitio interior Villa Alemana, que dio resultados para este estudio. El contexto de este entierro y el sitio arqueológico en general lo asocian con influencia Aconcagua-Inka y Diaguita-Inka como se observa en la cultura material, particularmente en la ofrenda funeraria de vasijas de cerámica (Vera Villarroel, 1985; Leguás Contreras, 2013). Los valores δ13C y δ15N para este individuo son indicativos de una dieta dependiente de recursos C4. De hecho, los datos isotópicos para este entierro de Villa Alemana del Período Tardío se encuentran dentro del rango de los reportados para los productores de maíz en Horizonte Medio Perú (Finucane, et al. 2006).

Tanto el valor δ13C (-11,4 ‰), y particularmente δ15N (11,4 ‰), son algo diferentes a los valores promedio observados para el Período Tardío en el área de Santiago (δ13C = 13,1 δ1.2 ‰ y δ15N = 5,9 δ 1,0 ‰) (Falabella, et al. 2008). El valor de δ15N para este individuo es el más elevado de todos los sitios del interior y sugiere una mayor ingesta de proteína animal alimentada con C4, proteína marina o ambas. Este individuo había alcanzado la edad adulta, por lo que cualquier impacto del efecto de la lactancia en el elevado δ15N puede ser descartado. A pesar de que Villa Alemana no es un sitio costero, se encuentra a unos 18 km del océano en el borde occidental de la cordillera de la costa, lo que puede haber facilitado el acceso a recursos costeros. En tanto el valor δ13C para este individuo es el más alto de todas las muestras analizadas de la colección de MHNV e indica una explotación sustancial de C4, posiblemente con algún aporte adicional de los recursos marinos.

Los datos isotópicos previos han revelado una reducción en la proporción de recursos de C4 en la dieta del Período Tardío en comparación con el Período Intermedio Tardío. En este estudio se observa una potencial diferencia en los patrones de consumo de maíz durante el Período Tardío entre la región de Valparaíso y las zonas de Santiago y Rancagua, lo que puede tener implicaciones relacionadas con la administración del imperio Inka en Chile central y con el control estatal de producción o suministro del maíz dentro del imperio. Sin embargo, con sólo una muestra del Período Tardío de esta colección, no es posible aseverar si los elevados valores de δ13C y δ15N de este individuo representan un aumento general en el consumo de maíz en la región de Valparaíso durante el Período Tardío y que puedan, a su vez, representar diferentes prácticas dietéticas durante este periodo en comparación con la región de Santiago, o bien se trata de sólo un individuo con valores δ13C y δ15N excepcionalmente elevados para este entorno geográfico y temporal.

CONCLUSIONES

Los resultados aquí presentados proporcionan evidencia a partir de análisis isotópico estable (δ13C y δ15N de colágeno óseo humano) para prácticas dietéticas desde el Período Alfarero Temprano hasta el Período Tardío de sitios costeros e interiores en la región de Valparaíso, Chile central. Los análisis de las muestras de la colección bioantropológica del MHNV demuestran variabilidad en las prácticas dietéticas y la explotación de recursos en diferentes contextos temporales y geográficos, particularmente en lo que respecta al consumo de C4 o de recursos marinos.

Se observaron diferencias entre las dietas de los individuos de sitios costeros en comparación con los sitios de interior. Donde el valor moderadamente elevado de δ15N y δ13C para las muestras costeras indica que los habitantes de esta zona estaban incluyendo algunos recursos marinos junto con los recursos terrestres en sus dietas, muy probablemente de niveles tróficos más bajos, como los moluscos. Por otro lado, los bajos valores δ15N para los grupos del interior sugieren una dieta terrestre, que pudo haber sido baja en proteínas animales o que incluyó el consumo regular de leguminosas fijadoras de nitrógeno. La amplia gama de valores de δ13C para estas muestras también manifiesta las diferentes prácticas dietéticas entre las muestras incluidas en el estudio, y particularmente apunta hacia una creciente inclusión del maíz en la dieta a lo largo del tiempo.

Estos resultados apoyan de manera general muchas de las conclusiones de la investigación isotópica anterior realizada en las áreas de Santiago y Rancagua (Falabella, et al. 2007; Falabella, et al. 2008). Sin embargo, se observaron algunas potenciales diferencias en los patrones dietéticos de esta región, los cuales pueden ser explorados de manera útil a través de nuevos análisis isotópicos con muestras adicionales dentro de la región de Valparaíso. Por ejemplo, todas excepto una de las muestras del Período Alfarero Temprano, incluyendo aquellas identificadas por los registros del museo como pertenecientes a la tradición Llolleo, mantuvieron una dieta terrestre fuertemente dependiente de C3, mientras que los datos isotópicos de los grupos Llolleo de Santiago y Rancagua indican que fueron ya adoptando maíz en sus dietas, como lo demuestran los valores más intermedios de δ13C (C3-C4). Se sugiere que las muestras del PAT incluidas en este estudio son de las

primeras etapas de la tradición de Llolleo, antes de una transición al cultivo de maíz, o bien representan una persistencia más prolongada de la dependencia de C3 en esta región.

Finalmente, aunque sólo se incluyó una muestra del Período Tardío en este estudio, los resultados de este individuo indicaron una dieta más dependiente del maíz en contraste con los patrones dietéticos previamente observados en las cuencas de Santiago y Rancagua, donde se observó una clara disminución del maíz en la proporción global de la dieta durante este período. El análisis isotópico adicional, junto con información contextual y datación absoluta de material de otros sitios en el área ayudará a aclarar algunos de estos hallazgos iniciales respecto a las prácticas dietéticas prehispánicas en la región de Valparaíso, zona central de Chile.

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Confirmo que, según mi leal saber y entender, la declaración de contribución del autor a continuación es precisa y que la contribución de Jaime Swift fue mayor que la de cualquier otro coautor.

Contribuciones de los autores

J.S. escribió el borrador inicial del manuscrito; J.O.P. y L.L.L. editaron el manuscrito para su publicación.

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I confirm that to the best of my knowledge, the author contribution statement below is accurate, and that Jaime Swift's overall contribution was greater than that of any other co-author.

Author Contributions

J.S wrote the initial manuscript draft; J.O.P, and L.L.L edited the manuscript for publication.

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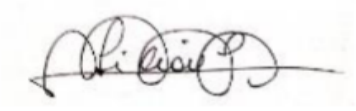
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Author Contributions

J.S. obtained the samples, interpreted the data and wrote the initial manuscript draft; N.F.B, and R.J.S obtained funding for the ^{14}C dates (with J.S. as student co-applicant) and edited the manuscript for publication.

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Por la presente doy permiso a Jaime Swift para utilizar nuestro trabajo conjunto *"A Radiocarbon Chronology for Estadio de Quillota in the Aconcagua Valley, Central Chile, with Reference to the Adoption of Intensive Maize Agriculture and Revisiting the Timing of Inka Influence on the Southern Frontier"* como contribución a su tesis de doctorado, que será presentada para su examen en la Universidad de Oxford.

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J.S. escribió el borrador inicial del manuscrito; J.O.P. y L.L.L. editaron el manuscrito para su publicación.

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Author Contributions

J.S wrote the initial manuscript draft; N.F.B, and R.J.S edited the manuscript for publication.

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