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Life in the Andean Northern Highlands: An Examination of Population Dynamics, Human Mobility and Dietary Change

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Publication Date
2020

UNIVERSITY OF CALIFORNIA
SANTA CRUZ

LIFE IN THE ANDEAN NORTHERN HIGHLANDS: AN EXAMINATION OF POPULATION DYNAMICS, HUMAN MOBILITY AND DIETARY CHANGE

A dissertation submitted in partial satisfaction
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

In

ANTHROPOLOGY

By

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June 2020

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ABSTRACT

Eden Washburn

Life in the Andean Northern Highlands: An Examination of Population Dynamics, Human Mobility and Dietary Change

The landscapes found within the Department of Ancash, Peru are incredibly diverse, closely stacked and present the inhabitants with a unique set of environmental demands. No landscape is perfectly suited to human habitation. As a consequence, humans learn, adapt to, transform or succumb to the pressures of their environment. But as a result of this process, humans are themselves changed in many dynamic ways. The research presented focuses on how human populations, as they interact with each other and their environment, develop adaptive strategies to mediate environmental pressures, and how the overarching cultural atmosphere influences the choices and behaviors of people.

This dissertation employs an interdisciplinary approach to the study of human-environment interaction that combines archaeology, osteology, and carbon, nitrogen ($\delta^{13}C$ and $\delta^{15}N$) and strontium ($^{87}Sr/^{86}Sr$) stable isotope analyses while focusing on two archaeological case studies from the Department of Ancash, Peru. Case Study 1 evaluates changing subsistence practices during the Late Preceramic (3000-1700 B.C.E.) and Initial Periods (1700-800 B.C.E.) at the archaeological site of La Galgada, Peru. Case Study 2 examines subsistence practices and the degree of residential mobility in the Callejón de Conchucos during the Late Intermediate Period (1000-1450 C.E.).

ACKNOWLEDGMENTS

This dissertation is the product of many years of research, and has been supported in so many ways by numerous people and institutions to whom I am immensely grateful. While incredibly challenging, I have been supported by amazing friends, colleagues, family and advisors who have made my journey so rewarding.

I would like to thank my committee members for their unwavering support and guidance throughout the years. In particular, I thank my advisor Lars Fehren-Schmitz for his patience, kindness, mentoring and encouragement as I continued to develop and grow intellectually over the last six years. Words cannot express my gratitude toward Lars for everything he has done for me. I also thank Jason Nesbitt for welcoming me into Peruvian Archaeology, and for without hesitation including me in his projects. It is with his support and guidance that I have succeeded in my research.

I would also like to thank Jelmer Eerkens who has supported me since my time at UC Davis as an undergraduate, introducing me to the wonders of isotopes and what they can tell us. I am forever grateful to Judith Habicht-Mauch who saw the potential in a quiet and insecure girl, welcomed me into the Anthropology Department at UC Santa Cruz, and encouraged me to blossom into the woman I am today. And I wish to thank Vicky Oelze for helping me to refine my writing and critical thinking over the last three years. I am eternally grateful for all of their support in the pursuit of my PhD.

While not officially on my dissertation committee, I also wish to thank Alison Galloway for introducing me to the world Forensic Anthropology, taking me under her wing, and mentoring me in so many ways. I have learned an enormous amount from her and vastly broadened my horizons.

I would also like to acknowledge my amazing cohorts: Cristina Verdugo, Kalina Kassidijakova, Naz Broomand and Bebel Ibarra. Words cannot express how much I have enjoyed working with them over the past years. I so appreciate their scholarship, interest and insights.

To the UC Santa Cruz Anthropology Department, I express my gratitude for the education, opportunities and experiences I have been given.

To the National Science Foundation and the Peder P. Johnson Scholarship Fund, thank you for believing in me and my research, and for funding this project.

In addition to all those who have supported me in my PhD, there have been many people throughout all of my educational experiences who have lifted me up to help me achieve the next milestone. To Dana Winitsky, Trish Langdon and Mike Wilson, I am eternally grateful to you for always encouraging and believing in me.

Finally, I would especially like to thank all my family and loved ones, especially my mother and my husband. Without your encouragement, love, sleepless nights, patience and support in every way, this would not have been possible. You mean everything to me.

CHAPTER 1

Introduction

The research presented in this dissertation assesses questions related to human environment interaction, diet, mobility and population interaction through time within the Department of Ancash, Peru, with a specific emphasis on the Andean highlands. The Andes mountains contain a rich diversity of ecological zones with changes in vegetation and climatic zoning distributed vertically along mountain slopes (Figure 1.1). These closely stacked, vertical environmental zones provide a variety of ecosystems that can be reached within a relatively short distance by traveling up or down a mountain slope, but they also extend horizontally over long distances (Beall, 1981, 2000; Forman, 1976; Lau, 2016; Quilter, 1991, 2011, 2014; Sanchez, 1977). People living within these environments face harsh environmental constraints such as climatic unpredictability (Brush, 1982; Contreras, 2010; Garreaud, 2009; Sandweiss et al., 2001; Sandweiss and Richardson, 2008; Strecker et al., 2007) and physiological challenges associated with high altitudes (Baker et al., 1968; Baker, 1976; Beall, 1981, 2000; Frisancho, 1975; Lindo et al., 2018; Mazess, 1975a, 1975b; Moore et al., 1998). These environmental constraints affect subsistence strategies, so in order to mediate these limitations, groups would develop adaptive strategies to actively manage and exploit their landscapes.

Figure 1.1: Ecosystems of the Peruvian north central highlands, photo taken near Huari, Peru

While the environment of the Andes presents its own set of unique challenges, groups also needed to navigate an incredibly dynamic socio-cultural landscape in which culture, religion, politics, status, individual and group identities, and community interaction all played an important role in shaping the lives of individuals and the organization of populations. These factors have the ability to change the ways in which people interact with their environments as well as with each other. Daily life in the Andes is an entanglement of environmental constrains as well as socio-cultural dynamics, all of which played an important role in subsistence practices and the extent and feasibility of movement throughout the region. How humans took advantage of, adapted to, altered or succumbed to their physical and socio-cultural environments through time is an important part of regional history that should not be overlooked.

All organisms, human and non-human, must in some way respond to the structural and functional characteristics of their environment. The study of human adaptability emphasizes the plasticity of human response to their environmental condition. This approach deals specifically with the problems faced by inhabitants of various ecosystems. It focuses on how human populations, as they interact with each other and their environment, attempt to adjust themselves to specific environmental problems, change the environment to make it more useable, and, in turn, how they are changed by these reciprocal dynamics (Golley, 1996; Haas, 1981; Moran, 1982, 2008).

This approach gives people a role as decision makers in changing, adjusting and transforming the physical environment without overlooking the fact that the people also change in the process (Moran, 1982, 2008). Adaptations to environments result from exposure to physical and chemical factors, from interaction with other species, and from the interaction of individuals within the same species (Moran, 1982, 2008). Theorizing and researching how humans adapt to environmental constraints requires researchers to focus on all levels of human response (individual, population and ecosystem). My research focuses on how individuals were able to adapt to their environmental constraints, navigate their physical and cultural landscapes all while under varying environmental and socio-cultural conditions. In addition, this research emphasizes the study of human-population dynamics and their effect on community structure within the Andean highlands.

My research is a “hybrid” dissertation composed of an introduction, two background chapters, three published or submitted articles, and a conclusion (outlined below). I focus on two archaeological case studies from the Department of Ancash: **Case Study 1** evaluates changing subsistence practices during the Late Preceramic (3000-1700 B.C.E.) and Initial Periods (1700-800 B.C.E.) at the archaeological site of La Galgada, Peru, while **Case Study 2** examines subsistence practices and the degree of residential mobility in the Callejón de Conchucos during the Late Intermediate Period (1000-1450 C.E.).

This research utilizes molecular anthropological methodologies including carbon, nitrogen ($\delta^{13}C$ and $\delta^{15}N$) and strontium ($^{87}Sr/^{86}Sr$) stable isotope analysis to address questions relating to diet and mobility. In addition, a future component of this research (discussed in Chapters 2 and 7), examines changes in population structure and evaluates human-population dynamics on the eastern slopes of the Andes, a region for which little is known about levels of population continuity and discontinuity through time. Results of my analyses provide new insights into population interaction as well as human-environment relationships, and how aspects of life are affected by the overarching socio-cultural landscape.

1.1 The Department of Ancash

The section of Peru that is the focus of this dissertation, formally recognized as the Department of Ancash (Figure 1.2) since 1839, is located to the north of Lima, the capital of Peru. The region presents a stunning variety of geographical spaces and has a deep history of human occupation spanning some 13,000 years (Amat, 2004; Diessl, 2004; Herrera, 2003; Ibarra, 2003, 2006, 2009, 2013, 2020; Orsini and Benozzi, 2017; Lau, 2016; Nesbitt et al., 2020; Tello, 1960). The incredible diversity of these landscapes includes high snow-capped peaks, rich intermontane valleys, well-watered eastern slopes descending into the Amazon jungle, and arid western slopes cascading to a coastal desert broken by irrigable valleys and fronting the productive fisheries of the Pacific Coast. It is within these dynamic environments that generations of people have lived, struggled, thrived and co-existed; states and empires have formed and collapsed, and groups have interacted and adapted to their physical as well as socio-cultural environments.

Figure 1.2: Map of Peru, Department of Ancash highlighted

This district traverses the northern Andes from the Pacific Coast to the Marañón Basin. To the west, the Cordillera Negra Mountains separate the coastal lowlands from the Santa River Valley. Further east, this region is longitudinally divided by the Cordillera Blanca and the Cordillera Huayhuash Mountain Ranges, which are among the tallest peaks in Peru, reaching upwards of 6000 meters above sea level (masl). East of the Cordillera Blanca lies the Callejón de Conchucos, a series intermontane valleys and river systems that drain into the Marañon River, one of the major tributaries of the Amazon (Figure 1.3).

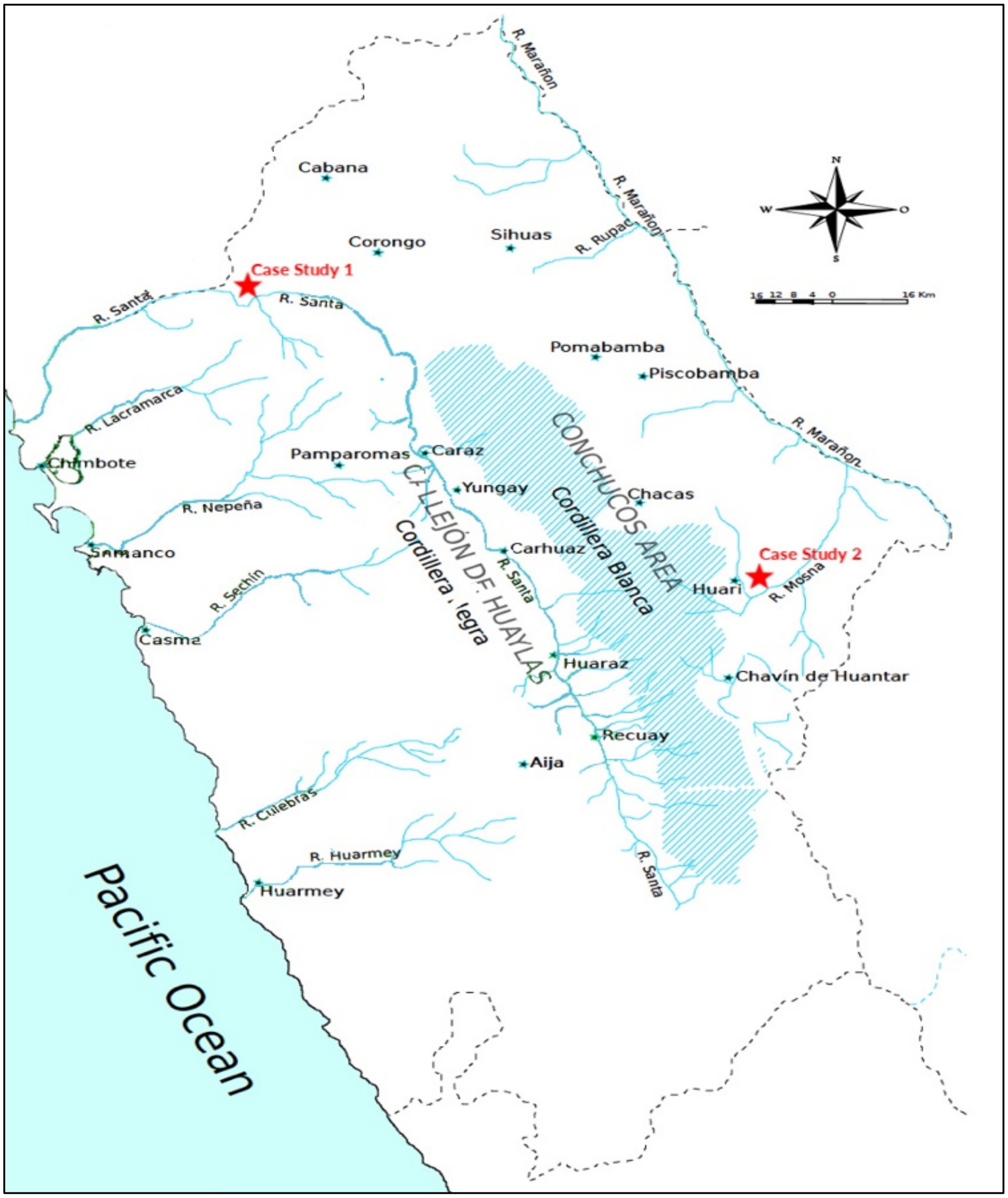

Figure 1.3: The Department of Ancash, Peru

As with many montane environments, local climate and vegetation vary greatly due to the elevation and location of different ecological zones (Pulgar Vidal, 1972, 1981, 1987; Tosi, 1960) (see Chapter 2 for further discussion). While the Andes provide a rich and diverse landscape, steep mountain slopes, high altitudes, and unpredictable climates present a set of unique challenges for inhabitants of this region. Given this variability in ecological zones, inhabitants developed adaptive strategies to exploit the landscape.

One such strategy proposed by John V. Murra, is referred to as 'verticality' or 'ecological complementarity' (Lau, 2016; Lynch, 1980; Moseley, 2001; Murra, 1972, 1985). Essentially, this adaptive strategy allows groups to actively access key resources from different vertically stacked environmental zones. This may be achieved by one community having satellites in different ecological zones but that are linked to each other through exchange and/or kinship relationships, in other words, a 'vertical archipelago' (Hirsch, 2018; Lau, 2016; Murra, 1972, 1985; Van Buren, 1996); or mobile groups who camped at different zones to access resources seasonally (Maxwell, 2011; Sanchez, 1977; Tomczak, 2003). Many groups in the Ancash almost certainly practiced at least a form of 'verticality' by pasturing animals in high-altitude grasslands, while also actively farming high-altitude crops in lands lower in elevation (Lau, 2016). However, it is not well documented or understood how the overarching cultural landscape affected the ability of these groups to practice traditional subsistence strategies, or how these factors impacted an individual's ability to move throughout the landscape.

1.2 Research Question and Case Studies

The Department of Ancash presents an ideal location to examine resource utilization, human-residential mobility, and population interaction through time due to its incredibly diverse landscapes and rich cultural history. My research question for this dissertation is as follows:

Question: How did the socio-cultural climate of the time affect facets of daily life, including subsistence practices, residential mobility, and population interaction?

Aspects of this question are discussed in the two case studies presented in this dissertation.

Case Study 1: Subsistence practices at La Galgada, Peru during the Late Preceramic (3000-1700 B.C.E.) and Initial Periods (1700-800 B.C.E.).

The Late Preceramic and Initial Periods in Peru were a time of emergent social complexity as illustrated by the construction of ceremonial architecture and permanent settlements (Burger, 1992; Pozorski and Pozorski, 2018; Quilter, 1991; Solis et al., 2001). A long-standing debate centers on the nature of the subsistence economies that supported this incipient complexity (Bonavia, 2008; Bonavia and Grobman, 1989; Haas and Creamer, 2004; Haas et al., 2013; Kidder and Lumbreras, 1963; Norr, 1995; Wilson, 1981). Though some scholars consider maize to have been an agricultural staple at this time, a growing body of archaeological research indicates that the use of maize spread irregularly throughout Peru and did not become a dietary staple until sometime after c. 800 cal B.C.E. (Blake, 2015; Burger, 2012; Burger and van der Merwe, 1990; Lanfranco and Eggers, 2010; Pozorski and Pozorski, 1979, 2006; Seki and Yoneda, 2005; Shady, 2006; Staller et al., 2006; Tykot et al., 2006).

La Galgada is located near the floor of the middle Tablachaca Valley of north-central Peru (Figure 1.4). At an elevation of 1,100 masl, La Galgada is positioned along the western slopes of the Andes and is approximately 80 km east of the Pacific shoreline. The site is situated in the *yunga* (500-2,300 masl) production zone. This zone is arid and warm, and agriculture is only feasible through irrigation. Despite these challenges, the western *yunga* is highly productive and its warm climate permits the cultivation of tropical and low elevation crops (Onuki, 1985). Using stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$) of human bone and dentine together with radiocarbon dating, this study estimates dietary composition, as well as changing subsistence strategies among 32 individuals interred within the ceremonial center of La Galgada (2300-1300 cal B.C.E.). The human remains from La Galgada were sampled at the *Museo Nacional de Arqueología, Antropología, e Historia del Perú*, Lima, where the archaeological materials from La Galgada are currently curated.

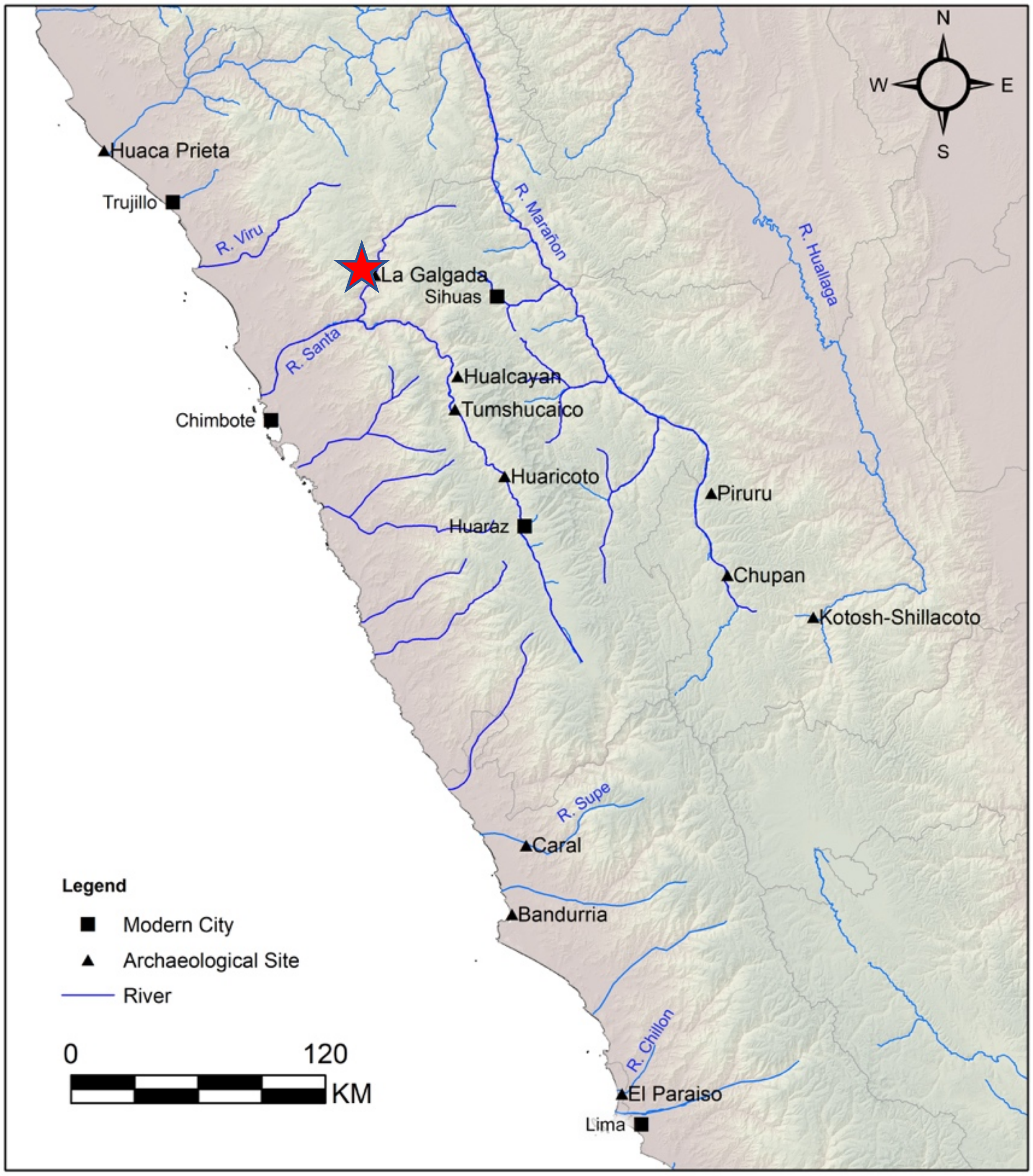

Figure 1.4: Map of Peru with the location of La Galgada (red star).

Case Study 2: Subsistence practices and the degree of residential mobility during the Late Intermediate Period (1000-1450 C.E.) in the Callejón de Conchucos.

My research in the Callejón de Conchucos began in 2016 when I visited Peru for the first time and began my collaboration with Dr. Jason Nesbitt and local archaeologist Bebel Ibarra. This piece of my dissertation was a two-step process: First, human remains from the Callejón de Conchucos were collected over the course of three field seasons (2016, 2018, and 2019). Second, it was necessary to create a regional $^{87}Sr/^{86}Sr$ isoscape (a spatially explicit prediction of isotopic variation across a landscape) that maps the strontium isotopes found within living systems for every geological formation found within the region, because the extent of $^{87}Sr/^{86}Sr$ variation had not yet been studied. This study, while fundamentally important for the interpretation of human $^{87}Sr/^{86}Sr$ values, also sparked my critique of past $^{87}Sr/^{86}Sr$ isotope studies which is further discussed in Chapter 5.

The Late Intermediate Period (LIP, 1000-1450 C.E.) in the Peruvian Andes is characterized by dramatically different cultural and climatological conditions when compared with the proceeding Middle Horizon (700-1000 C.E.) when the Wari empire exerted great influence over much of Peru (Bauer and Kellett, 2010; Brown Vega, 2009; Covey, 2008; Dean, 2005; Eitel and Mächtle, 2009; Fehren-Schmitz et al., 2014; Langlie, 2016; Mächtle et al., 2009; Parsons and Hastings, 1988; Pozorski, 1979; Tung et al., 2016). The collapse of the Wari Empire brought with it an era of political instability that has been documented throughout the Andes (Buzon et al., 2012; Isbell, 2004, 2008; Langlie and Arkush, 2016; Nash and Williams, 2004; Schreiber, 1987a, 1987b, 1992, 2001; Tung and Knudson, 2011; Tung, 2012; Tung et al., 2016). Recent research in the Andes has demonstrated that during the transitional period between the disintegration of the Wari Empire and the Late Intermediate Period, conflict between communities increased as independent regional polities of varying complexity began to emerge, expand, and collapse throughout the Central Andes (Álvarez and Greco, 2018; Arkush, 2008, 2011; Arkush et al., 2005; Arkush and Tung, 2013; Bauer and Kellett, 2010; Ibarra, 2020; Jolly and Kurin, 2017; Kellett, 2010; Kurin, 2013; Lofaro et al., 2018; Martiarena, 2014; Meddens and Branch 2010; Torres-Rouff et al., 2005; Tung, 2008; Tung et al., 2016). This study evaluates the nature of diet and degree of residential mobility during the second half of the LIP, based on isotope analysis of human remains recovered from the archaeological sites of Marcajirca, Jato Viejo and Ushcugaga, located in Callejón de Conchucos region of the north-central Peruvian highlands.

Marcajirca, located at 3800 masl, approximately 6km east of the City of Huari, and over 720km, northeast of Cuzco—the Inca heartland—presently covers 40 hectares, but it was likely over 100 hectares when fully inhabited (Figure 1.5 and 1.6). The site was occupied between ca. 1040-1640 C.E., with primary occupation during the Late Intermediate Period. The archaeological site of Jato Viejo (3850masl; 1150-1415 C.E.) is made up of a large, distinct rock outcropping with a series of natural caves. Human skeletal remains were found in four of the ten natural caves at the site (Figure 1.5 and 1.6). Like Jato Viejo, Ushcugaga (3500 masl) is a cemetery site, with no residential sector identified to date (Figure 1.5 and 1.6). The site is a large rockslide with burials found in natural crevasses created by the slide. Both sites are contemporary with Marcajirca but exhibit different mortuary practices.

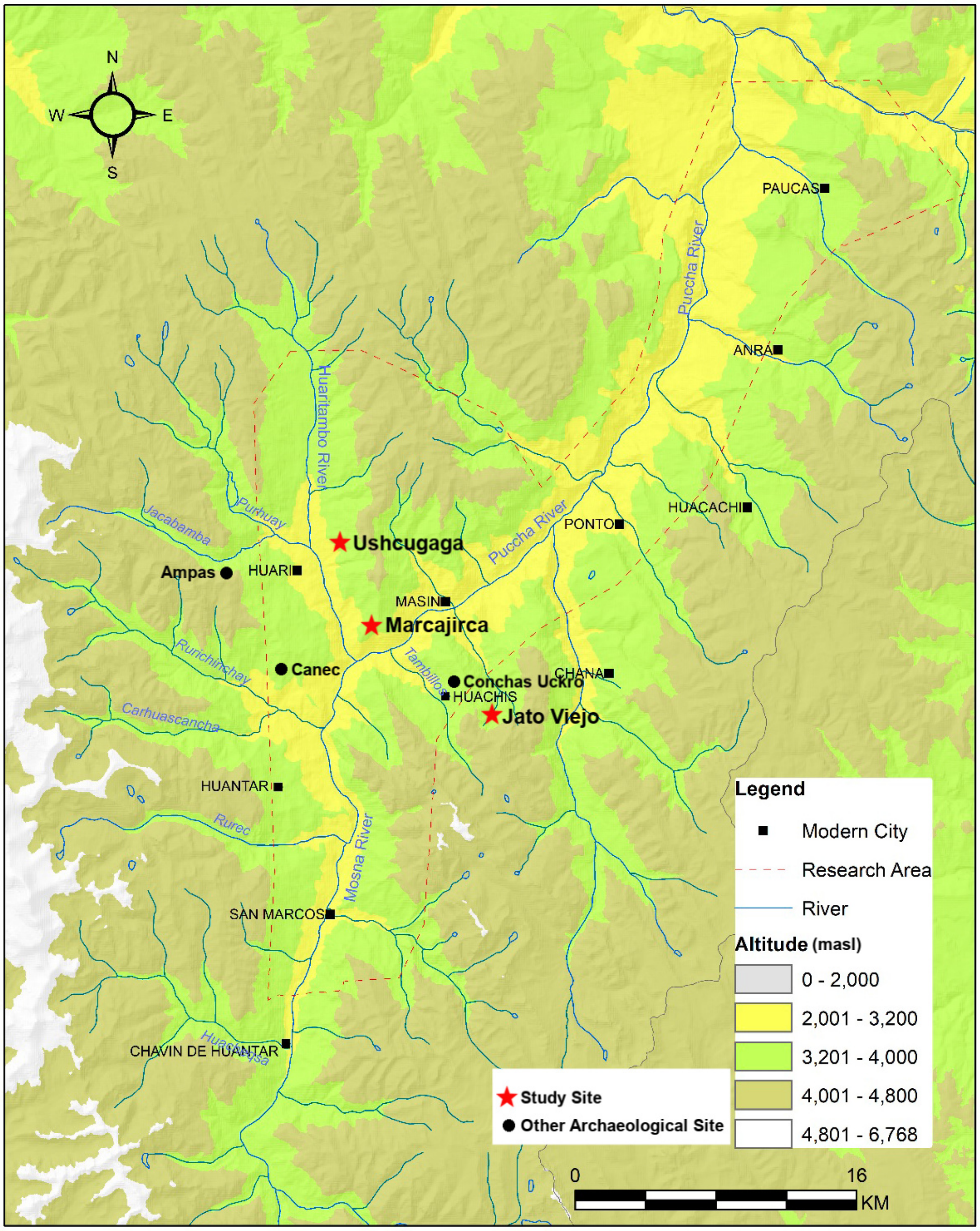

Figure 1.5: Puccha River and surrounding valleys, including the archaeological sites of Marcajirca, Jato Viejo and Ushcugaga

This study presents a multi-isotopic approach aimed at understanding individual life histories, focusing on $\delta^{13}C$ and $\delta^{15}N$ as well as strontium $^{87}Sr/^{86}Sr$ isotope data measured in human skeletal remains (M_1, M_2 or M_3 of 104 human individuals) found within the archaeological sites of Marcajirca (n=69), Jato Viejo (n=9) and Ushcugaga (n=26). Dentine samples from tooth roots were used for $\delta^{13}C$ and $\delta^{15}N$ isotope analysis, while enamel samples from tooth crowns were used for $^{87}Sr/^{86}Sr$.

Figure 1.6: Archaeological site of (A) Marcajirca, (B) Ushcugaga and (C) Jato Viejo

1.3. Chapter Overview

Chapter 2, entitled 'Background: The geography and archaeology of the Department of Ancash in the North-Central Peruvian Highlands,' discusses the geographical context for human settlement of the highlands located in the Department of Ancash. It outlines aspects of the region's geology, environmental zonation and climate. This chapter illustrates the region's rich archaeological history and the changing cultural/socio-political dynamics through time.

Chapter 3, 'Research Methodologies,' outlines the methods utilized in this research. In this chapter, I review the principles of stable isotopes in the biosphere, focusing in particular on the stable isotopes of those elements that trace human subsistence and mobility: carbon, nitrogen and strontium.

Chapter 4, published in the *Journal of Archaeological Science: Reports* (Washburn et al. 2020), evaluates the nature of subsistence during Late Preceramic Period (3000-1700 B.C.E.) and Initial Period (1700-800 B.C.E.) and discusses the uneven spread of maize agriculture throughout Peru. This case study focuses on the archaeological site of La Galgada Peru, an impressive ceremonial center (2300-1300 cal B.C.E.), from which large numbers of human burials have been documented. This study presents $\delta^{13}C$ and $\delta^{15}N$ stable isotope data measured in human skeletal remains (n=32) found at La Galgada alongside new radiocarbon dates of this material in order to understand past human diet, and the degree of dietary variation and change through time.

Chapter 5, submitted to *PlosOne,* critiques the use of strontium isotope (^{87}Sr/^{86}Sr) analysis as a method to examine past mobility and landscape use. The study presents the results of a systematic survey of modern flora and fauna (n=100) from 13 locations to map the bioavailable ^{87}Sr/^{86}Sr signatures of the Callejón de Conchucos, Department of Ancash in the Peruvian Andean Highlands, a region largely left out of previous archaeological research employing ^{87}Sr/^{86}Sr analysis in Peru.

Chapter 6 examines the socio-political climate of the Late Intermediate Period (1000-1450 C.E.). This study combines δ^{13}C and δ^{15}N and ^{87}Sr/^{86}Sr isotope analysis in order to evaluate the nature of diet and degree of residential mobility during the second half of the LIP, based on isotope analysis of human remains recovered from the archaeological sites of Marcajirca, Jato Viejo and Ushcugaga, located in Callejón de Conchucos.

Chapter 7 concludes the dissertation. In this chapter, I summarize the overall findings, outline new questions, and discuss future research in the Callejón de Conchucos.

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CHAPTER 2:

Background: The geography and archaeology of the Department of Ancash in the North-Central Peruvian Highlands

The department of Ancash, located to the north of Lima (the modern-day capital of Peru) covers a geographic area just under 36,000km^2. This region was formally recognized as the Department of Ancash in 1839 and comprises twenty administrative provinces. Within the Department of Ancash there is a variety of closely interconnected geographical spaces – the arid pacific coast, the Andes Mountains and the Amazonian lowlands (Burger, 1992; Lau, 2016; Pulgar Vidal, 1972, 1981, 1987; Quilter, 2011; Quilter, 2014). The sheer height of the Andes mountains (surpassed only by the Himalayas) and the aridity of the coastal desert that receives less rainfall than the Sahara or Gobi deserts, presents a series of environmental challenges to human occupation. However, within these diverse landscapes is a deep history of human occupation spanning some 13,000 years. To quote Richard Burger, “the biological and cultural adaptation of indigenous Andean peoples to these varied and extreme environments is in itself a remarkable testimony to the flexibility and creativity of humankind” (Burger, 1992:12).

2.1. Vertical landscapes of the Department of Ancash

The closely stacked landscapes that are characteristic of the Peruvian coast as well as the Andes mountains are formed by the tectonic movement of the Nasca Plate as it wedges itself underneath the South American Plate. The Nasca Plate moves at a rate of approximately 3.7 centimeters per year (Gregory-Wodzicki, 2000; Hoorn et al., 1995; Jordán et al., 1983; Montgomery et al., 2001; Strecker et al., 2007). At the point of contact, the Pacific Ocean floor bends downward into an oceanic trench as it is further subducted under the mainland (Jordán et al., 1983; Montgomery et al., 2001; Moseley, 2001). Through this tectonic energy, the continental margin was compressed, thrust up and buckled into the long parallel mountain ridges of the Andes.

The Pacific Coast

The Pacific Coast of Peru is a narrow strip of high temperature, arid desert intersected by numerous small rivers and intermittent streams, whose headwaters originate to the east in the Andes mountains (Figure 2.1). Rains rarely reach the desert coast of Peru. When rains do occur, they are usually associated with El Niño events. The western slopes of the Andes lie in a rain shadow (Figure 2.2) and the cold-upwelling Humboldt Current extracts most of the moisture that develops at sea. For this reason, vegetation below 2000 masl is extremely sparse, with thicker vegetation only found along riverbanks.

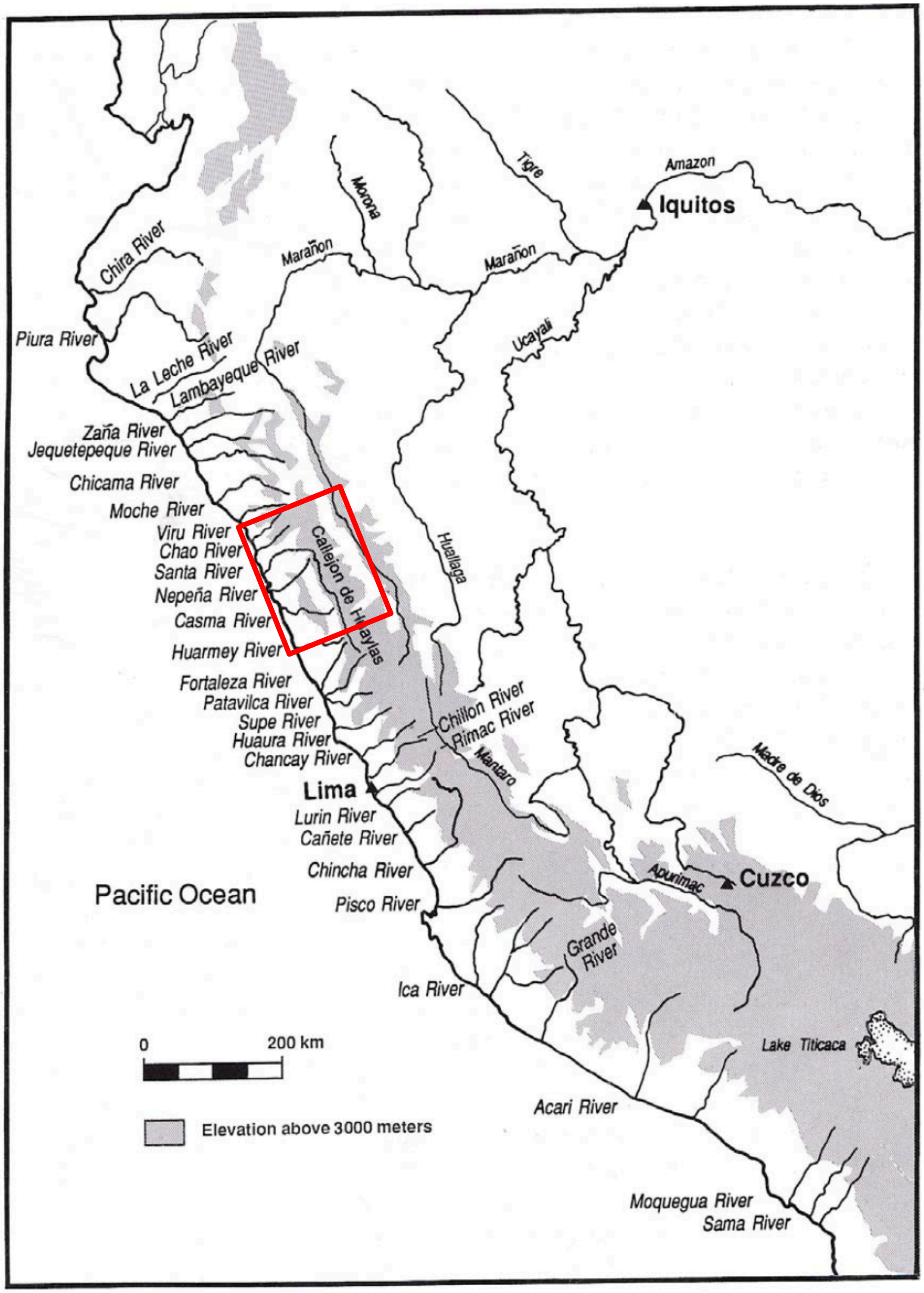

Figure 2.1: Major Rivers of the Central Andes (Burger, 1992:13); Ancash District roughly outlined by red box

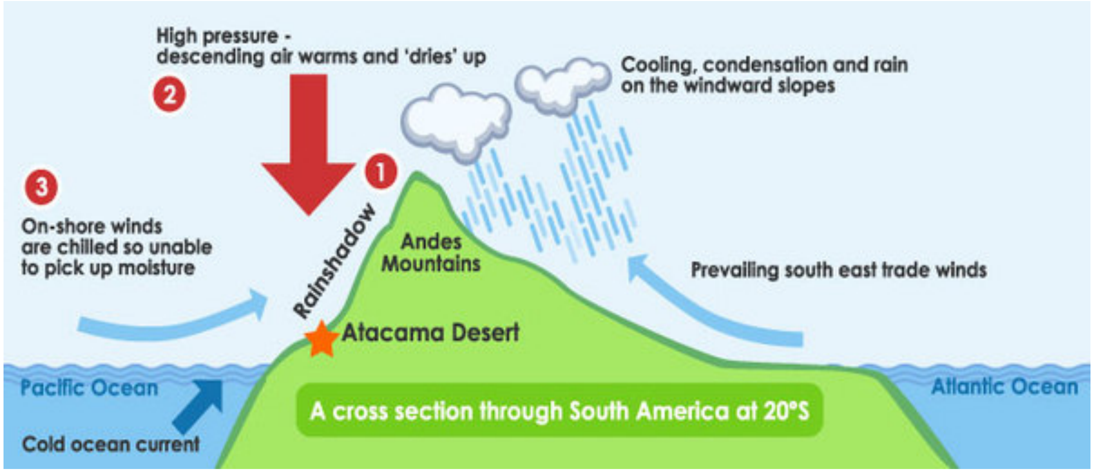

Figure 2.2: The rain shadow effect of the Peruvian Coast

The Pacific Ocean, on the other hand, provides an extremely rich set of natural resources, including a multitude of cold-water fish species, marine mammals, shellfish and avian resources (Moseley, 1975, 2005). Responsible for many of the distinct features of the coastal desert, the Humboldt Current of the Pacific Coast is composed of two sectors, a wide ocean current with relatively little marine life and a coastal current only 50-100km wide that follows the shoreline as they move up the coast of South America from Antarctica. The maritime resources found along the coast are so diverse and abundant that some of the earliest peoples of the Peruvian Coast achieved sedentism without a reliance on farming (Moseley, 1975; Quilter, 1991).

In the river valleys near the coast, natural vegetation type changes with elevation increases. When irrigated, these river valleys can be extremely productive, supporting a wide range of crops such as maize, peanuts, and chili peppers. The valleys of the coast presently contain 28 percent of Peru's cultivable land, compared with 55 percent in the highlands.

The Highlands

To the west, the Cordillera Negra with peaks over 5,000 masl, fronts the coastal desert. To the east, the remarkable Cordillera Blanca, which contains the highest peaks in the Andes mountain range, with more than sixteen glaciated peaks reaching upwards of 6,000 masl buffers clouds from the Atlantic carrying almost all of the Andes rainfall. Water, sourced from melting ice and seasonal rains, cascades down the Cordillera mountains to feed the two major river drainage systems of the Department of Ancash (Burger, 1992; Lau, 2016; Quilter, 2014). To the west is the Santa River and the valley system known as the Callejón de Huaylas, while to the east are the well-watered lands of the Callejón de Conchucos, a series intermontane valleys and river systems that drain into the Marañon River, one of the major tributaries of the Amazon.

The Andean terrain is bisected by rivers that form highland valley systems where most of human occupation in the Andes is located (Burger, 1992). Local climate and vegetation within these montane landscapes varies due to elevation, ecological zone and diurnal shifts in temperature (Pulgar Vidal, 1972, 1981, 1987; Tosi, 1960). The narrow valley floors and steep slopes of these intermontane valleys are uniquely suited for highland agriculture (Burger, 1992; Burger and van der Merwe, 1990). However, late season rains and early frosts can present a series of challenges to highland agricultural harvests. Freezing cold temperatures and frequent frosts set the upper limit of highland agriculture at approximately 4,000 masl.

The expansive year-round grasslands called *puna,* between 3,900 and 4,500 masl, are ideal for grazing camelids (e.g. Flannery, 1989; Flannery et al., 2016). In addition, many lakes found within this ecological zone support a variety of wild animals including deer, mountain cats, foxes, and viscachas (chinchilla-like rodents).

Just below the *puna* are the high-altitude lands known as *suni,* between 3,000-4,000 masl. Watered by seasonal rains, this ecological zone was actively farmed for key Andean crops such as potatoes (*Solanum* sp.) and other tubers [oca - *oxalis tuberosa*, ulluco - *Ullucus tuberosus*), quinua (*Chenopodium quinoa*), and lupins (Lupinus)] (Brush, 1976; Burger and van der Merwe, 1990). These plants can withstand the frequently windy and cold conditions characteristic of the *suni*.

Below the *suni* is another key ecological zone known as the *quechua,* about 2,000-3,000 masl. The *quechua* is generally frost free and especially suited for growing cultigens such as maize (*Zea mays*), beans (Fabacaea), squash (*Cucurbita* sp.), and a variety of other vegetables.

Rainfall is much more abundant along the eastern slopes of the Andes as moisture-laden winds that originate from the Atlantic coast collide with the eastern face of the Andes (Figure 2.2). Before the broad Amazonian drainage is the ecological zone known as the *ceja de montaña* up to between 2,000-3,000 masl. This zone is characterized by steep slopes covered by cloud forests in which low trees, mosses and ferns, as well as wild orchids can be found. The region has rich natural resources such as hardwoods, and significant diversity in foodstuffs.

The Amazonian drainage extends below the *ceja de montaña*. The headwaters of several major tributaries of the Amazon, such as the Marañon and Huallaga are found within this region and provide a natural link between groups living on the eastern slopes of the Andes and the eastern lowlands (Nesbitt et al., in press). However, little is known about the connection between groups living within this region.

As an example, the Andean-Amazonian Divide references the geographical region between the high peaks of the Andes mountain range and the lowland Amazonian rainforest (Dull et al., 2010; Gnecchi-Ruscone et al., 2019; Ibarra, 2009; Koch et al., 2019; Lathrap, 1970a, 1973; Olsen and Schaal, 2001; Santos-Granero, 2002; Tello, 1943, 1960; Walker and Ribeiro, 2011). This conceptual division references not only environmental differences and geographical distance, but also potential cultural separation between highland and lowland populations that could have inhibited extensive interaction. In Peru, archaeological interest in the North Central Andes has primarily focused on the study of population development by studying the rise and subsequent collapse of large-scale state economies. Furthermore, this tradition viewed the Cordillera Blanca as a geological barrier preventing direct west-east travel, thus limiting archaeological investigation on the eastern slopes.

In the Amazonian Basin, archaeologists such as Betty Meggers (1954) maintain that environmental instability prohibited formation of large, dense, and sedentary populations prior to European contact. A lack of archaeological evidence is used to support this hypothesis. This archaeological tradition views populations in the Amazon as static and unchanging from modern to ancient times, and as such the cultural differences between highland Andean and Amazon constrained extensive interaction (Balee, 1989; Barreto and Machado, 2001; Erickson, 2006; Heckenberger, 2008; Lathrap, 1970b; Meggers, 1991; Myers, 2004; Neves, 1995b; Roosevelt, 1994; Schaan et al., 2009; Vickers, 2006). However, this view of the Amazon is in direct conflict with early colonial reports which documented the presence of settlements along rivers so vast that explorers traveled miles by river to pass their full extent (Clement et al., 2015; Neves, 1995a, 1995b, 1998, 2008). In addition, many small communities are currently located on archaeological sites that show hints of previously being substantial, but very few have been excavated. New archaeological inquiries are just beginning to reveal the true scope of prehistoric human occupation in the Amazon Basin.

The headwaters of several major tributaries of the Amazon (i.e. Marañon and Huallaga) provide a natural link between groups living on the steep Andean slopes and the broad eastern lowlands below (Burger, 1992). The Amazonian floodplains remain poorly documented from an archaeological perspective, yet, even with limited evidence available, it appears that tropical forest groups played an important role in the development of Peruvian civilization.

Human adaptations to the Andes, more specifically the Andean northern highlands, have been fundamentally shaped by the distribution of available natural resources. Dramatic increases in altitude over relatively short distances result in a variety of *vertically defined ecological zones*. Because of these dramatic altitudinal changes, natural resources are specific to each geographical region. These closely stacked vertical environmental zones provide a variety of ecosystems that can be reached within a relatively short distance by traveling up or down a mountain slope, but which also extend horizontally over long distances (Quilter, 2014). In addition, seasonal variation increases with elevation. Plant-growth cycles are successively shorter at progressively higher altitudes, forcing populations living at high altitudes to utilize a wide range of *vertically defined ecological zones*. These environmental differences result in diverse subsistence strategies and economies throughout the Andes.

Mountain populations around the world (Guillet et al., 1983; Guillet, 1986; Schroeder, 1985) pursue farming, herding, and the exploitation of multiple ecological zones because stacked habitats with differing growing seasons are close together and the productivity of different zones fluctuates year to year (Moseley, 2001; Murra, 1972, 1985). In the Andes, people exploited this zonation to move produce up and down in elevation. This pattern of ecological zone usage is termed 'verticality; or 'ecological complementarity' (Lynch, 1971, 1980; Masuda et al., 1985; Murra, 1972, 1985). The verticality model focuses on the vertical stratification of resource zones and addresses limitations of life in the Andean highlands. Because of unstable, irregular, difficult conditions in high altitudes, populations occupying these environments often needed to expand their resource base by diversifying their own subsistence with items directly unavailable to them (Murra, 1972; Tomczak, 2003).

This strategy enhanced the variety and quantity of foods accessible and thereby reduced the risk of subsistence crises (Tomczak, 2003). In the northern highlands on the eastern slopes, however, the concept of "verticality" has seldom been applied to the extent that people additionally utilized lowland Amazonian landscapes.

The Ancash district of Peru provides an ideal location to conduct this research aimed at the reconstruction of population dynamics and subsistence changes through time, while examining potential similarities and differences in resource usage between archaeological sites. The district encompasses the full range of ecological systems found throughout Northern Peru, from the lowland Pacific Coast, to a range of altitudinal zones on both the western and eastern sides of the Cordilleras, to the lowland Amazonian ecosystems. Recent archaeological investigations of highland valleys in this region have illuminated a long population history and strategic ecozone selection from the late Initial Period through Inca colonization, with a shift in altitudinal and landscape preference for habitation over time. This dissertation focuses on changes in landscape utilization, subsistence practices, and population interaction across the Ancash district through time, with a specific emphasis on the 1) Late Preceramic (3000-1700 B.C.E.) to Initial Period (1700-800 B.C.E.) (*see Chapter 4*); 2) the Early Horizon (1000-200 B.C.E.) (*a future component of my research outlined in Chapter 7*) and 3) the Late Intermediate Period (1000-1400 C.E.) (*discussed in Chapter 6*).

2.2. Summary of the archaeological history of Peru

The Late Preceramic (3000-1700 B.C.E.) and Initial Periods (1700-800 B.C.E.)

The Late Preceramic Period (c. 3000-1700 cal B.C.E.) is of crucial importance to understanding the development of sociopolitical complexity in the Central Andes. Beginning in the early half of the third millennium B.C.E., groups living along the Peruvian coast and adjacent highlands initiated early traditions in the construction of monumental public architecture, which was associated with greater sedentism (Burger, 1992; Pozorski and Pozorski, 2018; Quilter, 1991; Solis et al., 2001; Washburn et al., 2020). The shift to more permanent settlements was enabled, in part, by cultural adaptations that allowed people to intensively utilize their environments. Many Late Preceramic highland developments occurred within the intermontane valleys of the present-day Department of Ancash, where groups began to settle in year-round communities and food production intensified, particularly in the raising of guinea pigs and camelids as well as the cultivation of various plants (Coutts et al., 2011; Lau, 2016; Quilter, 1991; Washburn et al., 2020). Crops such as squash, fruits, beans and tubers were cultivated through seasonal rains.

Rainfall agriculture played a crucial role in highland subsistence practices. The domestication of plants was well underway by 5000 B.C.E., and by 3000 B.C.E. it is likely that many food plants adapted to highland environments were already available. *See Chapter 4 for a full discussion of Late Preceramic subsistence practices.*

Major highland centers are found in a diverse range of environmental zones.

Examples of Late Preceramic Period highland centers include Kotosh (2000 masl) in the Huallaga Drainage (Izumi and Sono, 1963; Izumi and Terada, 1972), Piruru (3800 masl) in the Alto Marañon (Bonnier, 1997), Huaricoto (2500 masl) (Burger and Salazar-Burger, 1980, 1985, 1986), Hualcayán (3150 masl) (Bria, 2017), and Tumshucaico (2300 masl) (Bueno Mendoza, 2004) in the Callejón de Huaylas, and La Galgada (1100 masl) (Grieder and Bueno Mendoza 1985, 1988; Greider et al., 1981) in the Tablachaca River Valley. Despite the distances separating them, these Late Preceramic centers share key public architectural similarities referred to as the Kotosh Religious Tradition or 'KRT' (Burger and Salazar, 1980)**.**

KRT sites are known for their distinctive ritual structures, usually constructed out of clay or stone masonry (Burger and Salazar-Burger, 1986; Izumi and Sono, 1963; Izumi and Terada, 1972; Lau, 2016). These structures consisted of enclosed chambers, usually in circular shape. At the heart of each chamber was a central hearth or fire-pit. The largest temples were split-level with elevated benches that doubled as walkways and viewing spaces around the central fire-pit (Burger and Salazar-Burger, 1986; Izumi and Sono, 1963; Lau, 2016). The interior walls sometimes featured niches presumably for storage and/or the display of ritual items (Burger and Salazar-Burger, 1986; Solis, 2001; Lau, 2016). The structures would have been roofed with wooden beams and thatch, then surfaced with clay to provide smooth walls and ceilings (Burger and Salazar-Burger 1980, 1985, 1986).

The buildings of the KRT were well maintained in antiquity and were presumably created to provide an environment for religious ceremonies in which the burning of offerings was a crucial element (Burger, 1992). Notably, many of the structures of the KRT also exhibit episodes of ‘temple entombment’ in which chambers were intentionally sealed (Burger, 1992). The repeated burial of these chambers gradually produced mounds of considerable size that assumed the appearance of stepped, multi-tiered platforms, with small masonry superstructures (Burger, 1992; Lau, 2016).

In approximately 2000 B.C.E., the peoples of the Peruvian coast and adjacent highland groups began to produce pottery for cooking and storage (Burger, 1992) marking the transition from the Late Preceramic to the Initial Period in Peru. In the highlands, during the Initial Period, there is considerable continuity in settlement structure and subsistence practices. Many religious centers established in the Late Preceramic continued to be used into the Initial Period, including La Galgada, Huaricoto and Shillacota.

Highlands subsistence patterns largely depended on rainfall farming supplemented by hunting, with the range of available cultigens varying by ecological zone. There are, however, examples of irrigation in the middle and upper portions coastal valleys at sites such as La Galgada (Grieder and Mendoza, 1981; Grieder et al., 1988). In the northern highlands, valley slopes may have been used to grow maize and beans, while, lower elevation valley floors were co-opted to grow plants like manioc, which can be cultivated at lower altitudes (Burger and Van der Merwe, 1990).

The Early Horizon (800-200 B.C.E.) and Chavín de Huántar

Coastal subsistence changed significantly during the Early Horizon (800-200 B.C.E.), as intensive agriculture became dependent on constructed irrigation networks. While the diversity of cultigens continued from earlier times, the ratio of maize production to other crops may have increased (Pozorski and Pozorski 2006, 2018). Alternatively, in the highlands agricultural practice also intensified, but when compared with the coast there was not a significant increase in maize agricultural production prior to 800 cal B.C.E. For example, at iconic sites like Chavín de Huántar, Burger and van der Merwe (1990) note that while consumed, maize was not a staple crop. Although archaeological investigations indicate that a wide range of plant species and protein sources were consumed, the estimated proportions of these species in individual diets has been untested, especially by molecular methods.

Evidence suggests the ceremonial center of Chavín de Huántar was founded during the Initial period, ca. 900 B.C.E. (Burger, 1992; Rick, 2004; Rick et al., 2009). Many scholars today believe Chavín was the principal center of an influential religious cult that flourished during the 1st millennium BC and spread its distinctive material culture, practices and cosmology across different parts of the highlands and coast (Burger, 1992, 2008; Lau, 2016; Rick, 2004; Rick et al., 1998). The origins and early beginnings of the site are poorly documented from an archaeological perspective as they remain buried and difficult to access.

Located at the base of the eastern slopes of the Cordillera Blanca at an elevation of 3150 masl, this monumental ceremonial site sits at the junction of the

Mosna and Wacheksa Rivers. Below Chavín, the Mosna river merges with the Huari River to form the Puccha River that eventually empties into the Marañon. In addition, the site is positioned at the bottom of an intermontane valley that connects over the Cordillera Blanca into the Callejón de Huaylas and eventually joins the valley systems of the Pacific Coast, making this location advantageous for interregional interaction. Evidence of such interaction has been found in the form of various kinds of long-distance items from the coast and from the eastern montaña regions (Burger, 2008; Contreras, 2009, 2010, 2011).

The terrain surrounding the site is well-suited for high-altitude farming and camelid herding (Burger, 2008, Contreras 2010; Kembel, 2004; Miller and Burger, 1995; Rick 2004, 2009). There is abundant rainfall which presently supports rainfall agriculture on the valley slopes surrounding the modern-day town of Chavín.

Around the temple complex, a proto-urban settlement grew to over 50 ha (Burger, 2008). At the ceremonial center itself, the building history is long and complex, and its chronology continues to be refined (Burger, 1992; Kauffmann Doig, 1993; Kembel, 2008; Kembel and Haas, 2015; Rick, 2013; Rowe, 1962). The main construction consists of a series of platform mounds and plazas (Lau, 2016). Chavín's architecture resembles ceremonial architecture from previous time periods, such as the KRT (platform mounds, stone masonry, central staircases) and the Initial Period coastal centers (U-shapes, central mounds, lateral arms, circular plazas) (Burger, 1992; Lau, 2016, Rick, 2012).

Chavín's architecture is unprecedented in its extensive network of monumental entrances, accessways and interior stone-lined canals and tunnels. Many are called ‘galleries’ but they may have served many functions including drainage, storage, and providing access to ritual spaces (Kembel, 2008; Rick, 2008, 2013). They also played a crucial role in shaping the experiences of the residents and visitors of the ceremonial center. Complete architectural descriptions are found in a number of reviews (Burger, 2008; Kembel, 2008; Kembel and Haas, 2015; Lau, 2016; Lumbreras, 1977, 1993, 2007; Rick, 2004, 2008, 2013).

A key question in Andean archaeology centers on Chavin; how and why its influence spread. Some suggest that Chavín was the center of a state or military polity. But today, most would agree that Chavín de Huántar was a major center of an influence religious movement that relied on the efficacy of its provocative imagery (Burger, 1992; Lau, 2016; Rick, 2004). The ceremonial center of Chavín de Huántar is considered the epicenter of a religious cult that spread throughout parts of the highlands and the coast of Peru. This religious movement had great influence on other contemporary cultures and groups throughout the region. However, little is known about the people associated with this religious expansion. Very few domestic sites associated with common Chavín people have been identified. Rather, Chavín material culture was a ‘high-status’ elite culture associated with emerging nobles and priests (Burger, 1992; Rick, 2004, 2008, 2013).

Relatively little is known about Chavín settlements systems and rural life in highland Ancash during the Early Horizon, as only a few villages have been excavated (Ibarra, 2003). The bulk of archaeological research conducted at Chavín focuses on the site's monumental ceremonial complex and its role as a pan-regional center. Less is known about the origins of the founders of the site and their connections with nearby (~25km) populations like Canchas Uckro (c. 1100-800 cal B.C.E.). A future component of my research (*discussed in Chapter 7*) combines paleogenomic and strontium isotope ($^{87}Sr/^{86}Sr$) analysis to identify local and non-local individuals, and to investigate the genetic relationships between locals from Chavín and the surrounding valleys.

The Middle Horizon (700-1000 C.E.): The Wari and Tiwanaku

During the Middle Horizon (700-1000 C.E.) political centers within the Central Andes shifted from northern Peru and the Pacific coast to south central Peru, northwestern Bolivia and the Andean highlands (Isbell, 2008; Owen, 1994; Schreiber, 2001). Archaeological discussions of the Middle Horizon generally take a top down approach and center around the chronology of Wari and Tiwanaku development, the origin and spread of their distinctive iconography, the development of the two great capital cities, and the organization of their polities (Isbell, 2008). The Wari Empire (600-800 C.E.; the main focus of this summary) expanded from a core area in the Ayacucho Basin and came to control much of what is today coastal and highland Peru at its height (Schreiber, 1987b, 2001) (Figure 2.3). The Tiwanaku Empire (500-1000 C.E.) at its largest dominated the Altiplano Plains and stretched from the Peruvian coast to northern Bolivia and included parts of northern Chile (Knudson, 2008; Owen, 1994). Both the Wari and Tiwanaku empires spread their influence over vast areas of the Central Andes. However, how and why they spread, whether through religious cults, as military states/empires, or via some other means, continue to be topics of debate in Andean archaeology (Quilter, 2014).

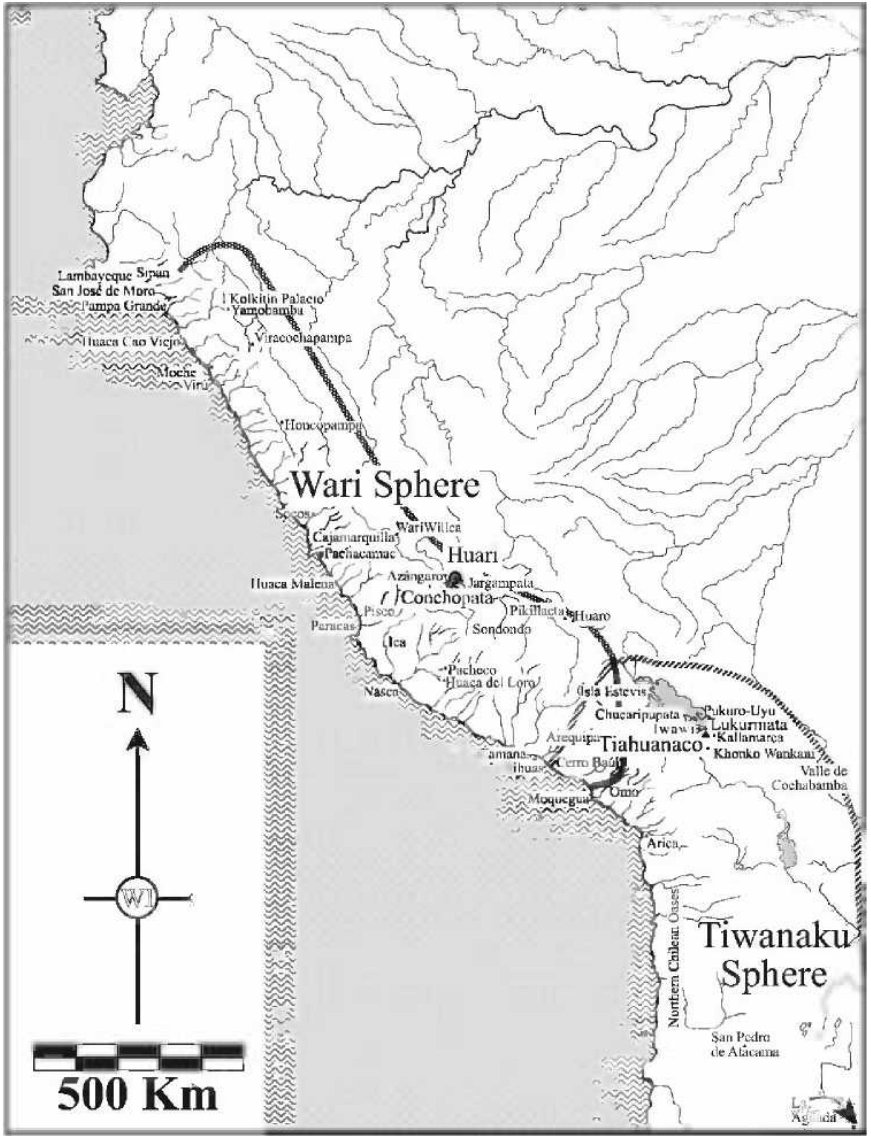

Figure 2.3: The Wari and Tiwanaku spheres of influence

The Wari polity has its origins in a large capital city. The city of Huari is located in the Ancash Region in Central Peru (Quilter, 2014). Huari has no freestanding stelae or large pyramids and there is no strong sense of organization such as a grid of streets or avenues (Quilter, 2014). Instead, the city grew through the construction of large walled compounds (Isbell, 1987). The compounds are usually rectangular, divided into square units each containing a central open patio surrounded by long, narrow rooms, which are often referred to as "Niched Halls" (Isbell and 1978; Quilter 2014). These compounds, sometimes with sections two or three stories high, may have been the residences of Huari elites, or else they may have been administrative centers (Isbell, 1987, 1997a, 1997b), workshops, or communities of different ethnic groups. It should be noted that similar compounds are found at Wari provincial sites throughout the empire (Isbell, 1997a; Quilter, 2014).

In general, the Wari appears to have acted more expansively in the highlands, especially in the southern highlands, than on the coast and in the north. However, the extent of control implemented in these various colonies differs significantly (Owen, 1994; Schreiber, 2001). Katharina Schreiber (1992) explains that the variability in the nature of Wari presence in different locations is due to a "mosaic of control" strategy. This suggests that Wari political investment was largely determined by a region's distance from the center, political organization, wealth potential, and tolerance to outside influence (Schreiber, 2001).

For example, in the Carahuarazo Valley during Wari occupation (ca. 600-800 C.E.) a number of changes occurred in the organization of local settlements. Prior to Wari incursion, the local settlement pattern was characterized by the presence of seven small villages and 17 hamlets that were probably seasonally occupied farming settlements (Schreiber, 1987a, 1987b). Most villages were located at elevations between 3,300 and 3,600 meters and comprised irregularly arranged round houses built of broken stone set in mud mortar (Schreiber, 1987a).

During Wari settlement of the valley, small villages were abandoned (Schreiber, 1987a). A Wari administration center, Jincamocco was established on a third abandoned village (Schreiber, 1987b). New villages were established at approximately 3,000 meters, and subsistence strategies changed from tubers to a reliance on maize agriculture; the establishment of terraces throughout much of the valley supports this transition (Isbell, 2004, 2008; Isbell and Young-Sánchez, 2012). In addition, a major road connecting this valley with both the south coast and the Wari core area was also constructed (Isbell and Young-Sánchez, 2012; Lau, 2016). Wari occupation of the Carahuarazo valley consisted of total reorganization and management of the local inhabitants, suggesting the need for more imperial structure for a variety of reasons.

The Wari and Tiwanaku empires remained a dominant presence during the Middle Horizon. They brought new methods of producing food and transporting staple and luxury goods from distant regions; established distant settlements with varying levels of reestablishment and control; and initiated a change in the religious, ceremonial and feasting practices within their boundaries. Both empires had substantial impact on the productivity and organization of their respective world and further on the lives of the individuals who lived within it

The cause of the collapse of both dominant empires at roughly the same time is still not well documented or understood. By 1000 C.E., both the great centers were abandoned, and the empires collapsed (Williams, 2002). There are two dominant theories to try and explain this rapid collapse:

The first is environmental stress (Binford et al., 1997; Fehren-Schmitz et al., 2014, 2017: Fehren-Schmitz and Georges, 2016; Kolata and Ortloff, 1989; Ortloff and Kolata, 1993). Toward the end of the Middle Horizon, a significant drought drastically lowered the water level of Lake Titicaca (Binford et al., 1997; Kolata and Ortloff, 1989; Ortloff and Kolata, 1993). The prolonged drought had devastating effects on the agricultural practices in the region (Kolata and Ortloff, 1989; Ortloff and Kolata, 1993). It is possible that this drought brought on various degrees of social unrest that undermined the rule of Tiahuanaco.

There is evidence to suggest that the Wari Empire faced similar environmental stress. The movement of highlanders to the coastal valleys, documented in the late Middle Horizon (e.g. Edwards and Schreiber, 2014), could indicate environmental stress related to a drought in the highlands that made agriculture and further subsisting difficult (Isbell and Young-Sánchez, 2012). Less is known about the collapse of the Wari Empire than Tiwanaku.

The second hypothesis related to the collapse of these two empires deals with internal social unrest. Bruce Owen and Paul Goldstein (2012) suggest that this social unrest may have been a more important factor than environmental conditions in the collapse of the Tiwanaku Empire. For example, in the Moquegua Valley during the late Middle Horizon, Chen-Chen style villages and temples were destroyed while Omo-style communities were untouched (Owen and Goldstein, 2012).

The rapid collapse of both substantial empires in the Central Andes undoubtedly had significant impacts on other settlements throughout the region. Sites with heavy imperial management were generally abandoned while smaller less influenced settlements began to reorganize.

The Late Intermediate Period (ca. 1000-1450 C.E.)

By approximately 1000 C.E., Wari power in the highlands was on the decline. Independent, regional centers began to appear through the Central Andes (Covey, 2008; Dean, 2005) marking the transition into the Late Intermediate Period (LIP). The proliferation of regional material styles, especially in pottery and architecture, indicates greater diversity in cultural groups and social organization (Bauer and Kellett, 2010; Brown Vega, 2009; Covey, 2008; Dean, 2005; Eitel and Mächtle, 2009; Fehren-Schmitz et al., 2014; Langlie, 2016; Mächtle et al., 2009; Parsons and Hastings, 1988; Pozorski, 1979). In addition, to changes in regional settlement patterns, the LIP is also characteristic for the decline in long-distance trade. The circulation of foreign ceramics, obsidian and marine shell slowed dramatically (Lau, 2016). By ca 1000 C.E., highland groups in the Department of Ancash, began to concentrate their residential settlements in more strategic locations, usually high on mountain ridges (Herrera and Lane, 2004; Herrera et al., 2007; Ibarra, 2009).

Two main factors appear to have contributed to this shift in settlement location. The first was access to the high puna grasslands that were favorable for grazing camelid herds (Lane, 2006). The second main reason seems to have been for defensive purposes (Buzon et al., 2012; Isbell, 2004, 2008; Langlie and Arkush, 2016; Nash and Williams, 2004; Schreiber, 1987a, 1987b, 1992, 2001; Tung and Knudson, 2011; Tung, 2012; Tung et al., 2016). Nearly all major LIP settlements were densely nucleated fortified sites. Such locations seem to have been key for the protection of the settlement from attacks and theft. *A more detailed description of the Late Intermediate Period can be found in Chapter 6.*

The Late Horizon

By the 15th Century AD, the Inca empire started to develop, first by consolidating power in the Cuzco region and then expanding across a large swath of western South America. At its peak, the Inca empire stretched from the northern Andes of Ecuador and Colombia to central Chile. From their capital city of Cuzco, the Inca came to rule their empire called Tawantinsuyu, or lands of the four quarters: Chinchaysuyu (north), Cuntisuyu (west), Qollasuyu (south), and Antisuyu (east). It was not until between AD 1460 and 1533 that the Ancash Highlands were under the domination of the Inca Empire. Even though the Inca tried to reorganize the region socio-politically, imposing some aspects of the Inca social organization, the conquest of the region was not an easy task. In general, it seems that the Inca mainly followed the local modes of social and economic organization in exchange for local labor services and loyalty.

The Inca used various strategies to conquer and integrate provincial groups across their empire. This involved cultivating alliances, collecting tribute, redistributing goods and occasionally resorting to military action (Burger and Salazar, 2004; Hemming, 2004; Rowe, 1946; Sarmiento de Gamboa et al., 2007). The Inca also built extensive bureaucratic infrastructure (provincial centers, waystations, roads and bridges) and forts, and resettled entire communities (D’Altroy and Schreiber, 2004; D’Altroy, 2001, 2005, 2014; Rowe, 1957). These strategies were used to control large swaths of land, to tax for resources, and to create the political community that was the Inca empire.

The collapse of the Inca Empire in 1532 C.E. brought back the resurgence of small communities with their own local traditions, but the eventual changes imposed on the region by the Spanish were drastic. 1575 C.E. marked a crucial time of transition in Andean history. The changes imposed by the Spanish reformation at the end of the 16th century brought about a depopulation of the Cordillera Blanca (Andrien, 2001; Joralemon, 1982; Loughlin et al., 2018; Lovell, 1992; Smith et al., 1970). All the lakes and woods were considered to be the property of the Spanish Crown and could only be used collectively by the population by paying a tax. In the 18th century, the local populations' access to resources from the highlands was compromised again by the privatization of land and the creation of haciendas (Quilter, 2014). Spanish colonization imposed new constraints to keep order in the country, destroying the economic base of Andean society in just a few years.

2.3. Summary

This chapter examined the geographic and geological settings and a brief summary of the archaeological history of the Andes. It is within these dynamic physical and cultural landscapes that populations modified, adapted to and altered their environments. The following chapters of this dissertation document changes in subsistence practices, mobility patterns and population interactions through time in an attempt to begin to understand the complex social and physical entanglements of daily life in the challenging landscapes of the Peruvian Andes.

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CHATPER 3

Research Methods

Within biological anthropology, biochemical analyses such as stable isotope and human paleogenomic studies have become more prevalent with the development of new and innovative methodologies. These techniques have allowed researchers to examine human population dynamics as the result of internal and external environmental or cultural stimuli. Both stable isotope and ancient DNA (aDNA) analyses allow researchers to gain insight into cultural processes and individual choices that might have contributed to human-environment relationships on a scale that with standard archaeological practice would otherwise be difficult to observe.

This chapter examines carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$), and strontium ($^{87}Sr/^{86}Sr$) isotope analysis as well as aDNA in order to establish a baseline review of each methodological approach.

3.1 Isotope definitions

Different isotopes of an element have the same number of protons in the nucleus (i.e. the same atomic number) but differ in the number of neutrons and therefore in the atomic mass. Isotopes are broken down into three specific categories: radioactive, radiogenic and stable. Radioactive isotopes undergo decay at a constant rate, during which the nucleus of the unstable parent element loses energy by emitting radiation. There are many different types of radioactive decay. In the case of Carbon-14 (^{14}C – 6 protons and 8 neutrons) a radioactive isotope of carbon undergoes a process of transmutation where due to the loss of energy a neutron decays into a proton, emits an electron, and with 7 protons instead of 6 the atom is transformed into Nitrogen-14 (^{14}N). This process of decay operates at a known rate, losing half of its carbon-14 every 5,730±40 years. Radiogenic isotopes are stable isotopes that are produce from the decay of radioactive isotopes (^{87}Sr for example, which is the product of the decay of ^{87}Rb). Stable isotopes, on the other hand, remain constant through time and do not undergo decay.

3.2 Isotopes and their behavior within the biosphere

Effects such as photosynthesis or synthesis of tissues often lead to a partitioning of isotopes. Different isotopes of an element undergo the same chemical and physical reactions but differences in mass influence the rate and extent of reactions through two processes (Schoeninger, 1995; Sulzman, 2007). First, heavier isotopes have a lower kinetic energy than lighter isotopes, and therefore travel at a slower velocity, resulting in differences in reaction kinetics (Sulzman, 2007). Second, the atomic mass of an isotope determines the vibrational energy of the molecule (Sulzman, 2007). Heavier isotopes vibrate more slowly and form stronger bonds and as such molecules containing heavier isotopes react more slowly (Faure, 1977; Faure and Mensing, 2005; Sulzman, 2007). Due to these differences, isotopes are sorted or experience a fractionation effect during chemical, physical and biological processes. This fractionation effect can result in significant differences between the isotope ratio of the substrate (e.g. diet) and the product (e.g. tissue) (Cerling and Harris, 1999;

O'Leary, 1981; Schoeller, 1999). Typically, the heavier isotope is discriminated against (Hoefs, 2008).

The fractionation factor, α, is the ratio, R, of heavy to light isotopes in the product (i.e., tissue) to the ratio of heavy to light isotopes in the substrate:

$$\alpha = \frac{Rp}{Rs}$$

Isotope enrichment, ε, is the result of fractionation:

$$\varepsilon = (\alpha - 1)\ x\ 1000$$

Stable isotope ratios are measured as the ratio R. Because the isotopic differences between materials are very small, the ratio is expressed as parts per thousand:

$$\delta(‰) = ((R_{sample}/R_{standard}) - 1) \text{ x } 1000$$

This notation is used for light isotopes (i.e., C, H, O, N), whereas some heavier isotope systems (i.e. Strontium (Sr) are reported using ratios themselves (i.e. $^{87}Sr/^{86}Sr$). The more negative δ value, the more depleted in the heavier isotope relative to a standard, while a more positive a δ value indicates the sample is enriched in the heavier isotope relative to a standard.

3.3 Reconstructing past diets through stable isotope analysis

The use of stable isotope analysis as a methodological approach has been applied in a variety of academic fields including geology, ecology, chemistry, and archaeology. In archaeology the study of carbon, nitrogen and strontium isotopes have been engaged to address a wide range of human behavior like dietary strategies (Ambrose and DeNiro, 1986a; Barrett et al., 2001; Eerkens et al., 2011; Finucane et al., 2006; Fuller et al., 2006b; Katzenberg and Weber, 1999; Keegan and DeNiro, 1988; Kellner and Schoeninger, 2008; Larsen, 2000; Newsome et al., 2004; Norr, 1995; Pozorski, 1979; Schoeninger et al., 1983; Schurr, 1997; Tauber, 1981; Tomczak, 2003; Walker and DeNiro, 1986), mobility patterns (Burns et al., 2012; Eerkens et al., 2014; Jorgenson et al., 2009; Slovak et al., 2009) and kinship relations (Bentley et al., 2003; Esparza et al., 2017; Haak et al., 2008; Price et al., 2002; Tafuri et al., 2006). Biological tissues in the human body are synthesized from ingested food and water that may have different underlying isotopic compositions, or signatures, which are subsequently recorded in human biological tissues, such as bone or tooth collagen (Eerkens et al., 2011; Tieszen and Fagre, 1993).

Collagen is a protein that helps form connective tissues, including in bone and dentin (Tieszen and Fagre, 1993). However, tooth and bone collagen have different formation patterns. In bone, collagen is continually remodeled throughout an individual's lifetime. As a result, isotopic data collected from bone collagen, found in the cortical structure of bone, informs on food and water consumed over the last several years of an individual's life. In contrast, teeth do not remodel, and thus preserve an isotopic signature of dietary behavior over the temporal window during which the dental tissues formed (Hillson, 1996).

3.4 Carbon

The three most common naturally occurring isotopes of carbon are ^{12}C (stable), ^{13}C (stable), and ^{14}C (radioactive). ^{12}C is the most abundant form of carbon, making up 98.93% of the total Earth carbon, while ^{13}C forms the remaining 1.07% (Chisholm et al., 1982, 1983; Farquhar et al., 1989). ^{14}C is found only in trace amounts on Earth, approximately 1 part per trillion (Farquhar et al., 1989; Stuiver and Quay, 1980). The amount of ^{14}C in the atmosphere and in living organisms remains almost constant until death when it begins to decay. Stable isotope analysis of carbon measures the ratio of ^{13}C to ^{12}C, expressed in a normalized form as $\delta^{13}C$. Values are reported relative to an international standard, Vienna-PDB (VPDB). VPDB has relatively more ^{13}C than most biological materials, so samples typically have a negative $\delta^{13}C$ value.

In terrestrial systems carbon enters the food web through plants, which fixate carbon from the atmosphere. Today, atmospheric CO_2 has a $\delta^{13}C$ of -8‰ compared to -7‰ in the mid-1950s. This value has been decreasing from the burning of ^{13}C-depleted fuels since the latter half of the 19th century (Francey et al., 1999; Kellner and Schoeninger, 2007). As atmospheric CO_2 is taken up by plants, the heavier isotope is discriminated against, resulting in more negative plant $\delta^{13}C$ values relative to that of atmospheric CO_2.

Carbon is an essential building block of life found in all living organisms on earth. Furthermore, it is the second most abundant element in the human body by mass after oxygen. Humans, by the food consumed, take up carbon into biological tissues (DeNiro and Epstein, 1981; O'Leary, 1981). Carbon isotope dissimilarities between human populations are largely the result of differences in ingested foods. $\delta^{13}C$ values can reflect both the carbon source of dietary protein as well as potential variations in ingested plants with a prey-predator collagen enrichment factor of between 0-2‰ in $\delta^{13}C$ values (Bocherens and Drucker, 2003).

Differences in $\delta^{13}C$ values exist in plants as a result of three carbon-fixing photosynthetic pathways (DeNiro and Epstein, 1978; O'Leary, 1988; Smith and Epstein, 1971; Smith, 1972). These photosynthetic pathways for atmospheric CO_2 fixation include C_3 (Calvin Cycle), C_4 (Hatch-Slack pathway), and CAM (Crassulacean Acid Metabolism).

Found in trees, shrubs, herbs and grasses with a cool growing season (like the Central Andes), the C_3 pathway produces an average $\delta^{13}C$ value of approximately -26.5‰ in plant tissue (O'Leary, 1988; Tieszen and Fagre, 1993; van der Merwe and Medina, 1989). Variation in $\delta^{13}C$ values within C_3 plants can occur in dry environments, with C_3 plants in open-air sites typically enriched in ^{13}C with $\delta^{13}C$ values as high as -22‰ (Martinelli et al., 1991; Smith and Epstein, 1971). In contrast, some forested areas display a so-called canopy effect due to incomplete atmospheric mixing (Bonafini et al., 2013; Drucker et al., 2008; Finzi et al., 1998; Tykot, 2004; Van der Merwe and Medina, 1991). C_3 plants growing under these closed canopies (like in the Amazon Rainforest) (Martinelli et al., 1991) are generally depleted in ^{13}C, with $\delta^{13}C$ values as low as -37‰ (Ambrose and DeNiro, 1986a, b; Van der Merwe and Medina, 1991). In addition to pathway variation, $\delta^{13}C$ values vary with aridity

(Ehleringer et al., 1987; Epstein et al., 1997; Stowe and Teeri, 1978; Tieszen et al., 1997). For example, C_3 plants can become enriched in ^{13}C during periods of drought. The aridity effect of ^{13}C enrichment is much less pronounced in C_4 plants (Ambrose and DeNiro, 1986a, b).

On the other hand, grasses native to hot, arid environments, including domesticates such as maize (*Zea mays)*, millet, amaranthus including kiwicha (*Amaranthus caudatus*) and sugarcane, exhibit the C_4 photosynthetic pathway and have an average $\delta^{13}C$ value of -12.5‰ (Finucane et al., 2006; Hattersley, 1982; van der Merwe and Medina, 1989; Waller and Lewis, 1979), but also can differ within C_4 grasses. The differentiation in isotopic composition between C_3 and C_4 plants has been be used to track the spread of Maize agriculture throughout the Americas (Bender et al., 1981; Blake, 2015, 2016; Burger and van der Merwe, 1990; D'Altroy, 2001; D'Altroy and Schreiber, 2004; Finucane et al., 2006; Finucane, 2007, 2009; Fritz, 1990; Gil et al., 2006; Goldstein, 2003; Hastorf, 1991; Kellner and Schoeninger, 2008; Slovak et al., 2009; Slovak and Paytan, 2011; Tung et al., 2016; Tung and Knudson, 2018; Tykot et al., 2006; Warinner et al., 2013; Wilson et al., 2007).

The CAM pathway occurs in desert plants and succulents (i.e. prickly pears) and have intermediate $\delta^{13}C$ values (Griffiths, 1992; Osmond et al., 1973; Troughton and Card, 1975). Furthermore, $\delta^{13}C$ values for a single species can fluctuate throughout the year (Griffiths, 1992; Lowdon and Dyck, 1974).

A wide range of $\delta^{13}C$ values have been recorded for aquatic plants (Boon and Bunn, 1994; Maberly et al., 1992; Marčenko et al., 1989; Osmond et al., 1981). Aquatic primary producers assimilate carbon from dissolved CO_2 but can also use HCO_3 (Bain and Proctor, 1980; Nielsen, 1947; Osmond et al., 1981; Raven, 1970). Most aquatic plants utilize the C_3 photosynthetic pathway (Keeley, 1990; Keeley and Sandquist, 1992).

3.5 Nitrogen

There are two common naturally occurring isotopes of nitrogen, ^{14}N and ^{15}N. Stable isotope analysis of nitrogen measures the ratio of ^{15}N to ^{14}N and are expressed in a normalized form as $\delta^{15}N$. Nitrogen, a requirement of organisms to produce amino acids, makes up 78% of the atmosphere. However, nitrogen cannot be absorbed directly by most plants until it is converted into useable compounds through the Nitrogen Cycle. During the Nitrogen Cycle, plants take up fixed nitrogen from the soil with the aid of N_2 fixing bacteria. These plants can have varying ^{15}N values due to moisture, soil pH, and the association with soil microbes and fungi (Franche et al., 2009).

Nitrogen is further taken up into human biological tissues through ingested dietary protein. The estimated level of fractionation from diet-to-body (tissue) is between 3-5‰ (DeNiro and Epstein, 1981; Hedges and Reynard, 2007; Minagawa and Wada, 1984; Sealy et al., 1987); however, this value is based on the assumption that enrichment in mammals, including humans, is relatively similar. Though somewhat debated (Robbins et al., 2005), fractionation seems to have a positive correlation with increases in dietary protein. In other words, individuals with a high protein diet exhibit relatively high $\delta^{15}N_{\text{diet-body}}$ fractionation (Pearson et al., 2003; Sponheimer et al., 2003). This observation is based on the idea that ^{14}N is preferentially lost in urea following protein metabolism, increasing $\delta^{15}N$ values in tissues synthesized within the human body (Pearson et al., 2003). In contrast, individuals with a low protein diet utilize most of the available nitrogen to build tissues and thus have lower $\delta^{15}N_{\text{diet-body}}$ values (Pearson et al., 2003).

Traditionally, the $\delta^{15}N$ composition of human bone collagen has been used to inform on the trophic level of an individual's diet as well as the possible environment in which protein was acquired (Adams and Sterner, 2000; Bocherens and Drucker, 2003; Cabana and Rasmussen, 1996; Hedges and Reynard, 2007; Hesslein et al., 1991; Schoeninger, 1985). However, more complicated processes might be involved. For example, Hedges and Reynard (2007) assess to what extent inter-individual variation in ^{15}N enrichment can be interpreted as dietary as opposed to physiological or genetic differences. In addition, recent research has illuminated additional factors that could potentially affect isotopic results such that trophic level shifts could be variable under certain conditions, including nutritional stress (Fuller et al., 2005; Hobson et al., 1993), starvation (Haubert et al., 2005; Mekota et al., 2006), and/or growth (Hobson and Clark, 1992; Hobson et al., 1993).

Research has shown environmental trophic levels become enriched in the heavier ^{15}N vs. ^{14}N (Schoeninger, 1985). $\delta^{15}N$ increases approximately 3‰ per trophic level (Schoeninger and DeNiro, 1984). This effect allows biologists and archaeologists to reconstruct food webs in both modern and ancient environments (Eerkens et al., 2017; Minagawa and Wada, 1984; Tieszen and Fagre, 1993).

In addition, stable isotope analysis of nitrogen has also been used to differentiate between sources of protein (i.e. marine, terrestrial, and freshwater). For example, marine fish can be recognized as dietary components through elevated $\delta^{15}N$ values (Barrett et al., 2001; Chisholm et al., 1983; Moore, 1992; Richards and Hedges, 1999; Schoeninger and DeNiro, 1984; Schoeninger, 1985; Tauber, 1981). Studies of animals raised on diets for which the nitrogen isotopic compositions were known, demonstrate that the $\delta^{15}N$ values of animal tissues are determined by the $^{15}N/^{14}N$ ratios of their diets (e.g. DeNiro and Epstein, 1981). Nitrogen isotope ratios acquired through diet ultimately depend on the $^{15}N/^{14}N$ ratios of the plants at the base of the food chain. Marine plants generally have higher $\delta^{15}N$ values than terrestrial plants and this difference in ^{15}N content is carried up complex marine food chains, causing marine animals to have higher $\delta^{15}N$ values than those of terrestrial animals (Schoeninger et al., 1983). As a result, humans foraging in/depending on marine ecosystems can be identified by an average of 9‰ higher $\delta^{15}N$ values than terrestrial feeders (Ambrose et al., 1997; Mays and Beavan, 2012; Reitsema et al., 2010; Schoeninger and DeNiro, 1984; Schulting et al., 2008; Walker and DeNiro, 1986).

In order to analyze the extent of marine and freshwater fish contributions in human diet, both carbon and nitrogen values should be considered. Freshwater fish have variable isotopic signatures, primarily reflecting the differences in the concentration of dissolved inorganic carbonates, which are the carbon source of many aquatic plants (Bonsall et al., 1997; Finucane et al., 2006). The carbon isotope ratios of marine and freshwater organisms are variable depending on local ecological conditions (Cook et al., 2001; Hedges and Reynard, 2007; Katzenberg and Weber, 1999; Schoeninger et al., 1983), and often overlap with those of terrestrial plants and their consumers (Chisholm et al., 1982, 1983; Deines, 1980; Kellner and Schoeninger, 2007). These foods typically have higher nitrogen isotope values than their terrestrial counterparts, presumably a consequence of food-web complexity.

When compared with individuals feeding within marine or freshwater ecosystems, terrestrial feeders have relatively low $\delta^{15}N$ values (Bender et al., 1981; DeNiro and Epstein, 1978; Schoeninger et al., 1983). Furthermore, it is generally assumed that primary consumers such as wild herbivores will have $\delta^{15}N$ values that immediately reflect the local grazing vegetation, resulting in lower $\delta^{15}N$ values (Hedges and Reynard, 2007). It therefore becomes important to gain an understanding of the ecology of the environment individuals inhabited. If available, the analysis of directly associated fauna can provide information on the isotope baseline variation of dietary items and should ideally be established using associated archaeological fauna at a given site. Modern environmental samples can also be useful to aid the interpretation of ancient isotope values.

In addition to indicators of protein source, physiological factors such as pregnancy, lactation, and consumption of breast milk in infants, and/or starvation may affect $\delta^{15}N$ values. For example, nitrogen isotopic studies have been increasingly applied to the study of parental investment through the analysis of age of weaning identifiers (Clayton et al., 2006; Dupras et al., 2001; Eerkens et al., 2011; Eerkens et al., 2017; Fuller et al., 2003; Fuller et al., 2006a; Katzenberg and Pfeiffer, 1995; Richards et al., 2002; Schurr, 1997, 1998; Tsutaya and Yoneda, 2013). This approach relies on the notion that there is a trophic level enrichment between mother and infant (Clayton et al., 2006; Dupras et al., 2001; Eerkens et al., 2017). When breastmilk comprises all of the diet, $\delta^{15}N$ values of an infant should be one trophic level higher than food consumed by the mother (Clayton et al., 2006; Eerkens et al., 2011; Eerkens et al., 2017; Fuller et al., 2006a; Richards et al., 2002; Tsutaya and Yoneda, 2013). During the weaning process, as a child is transitioned to solid food, $\delta^{15}N$ should drop by approximately 3‰, into the range of other adults, assuming a weaned offspring's diet is similar to the parent. In fact, infants often decrease more than 3‰ in $\delta^{15}N$, a phenomenon still not fully understood (Fuller et al., 2003; Fuller et al., 2006a; Fuller et al., 2006b). Following weaning, $\delta^{15}N$ will reflect the trophic level of the weaning food and early childhood diet (Eerkens et al., 2011; Eerkens et al., 2017; Fuller et al., 2006a; Fuller et al., 2006b; Schurr, 1997; Tsutaya and Yoneda, 2013).

3.6 Strontium

Strontium (Sr) is an alkaline metal, with four naturally occurring stable isotopes: ^{84}Sr (~0.56%), ^{86}Sr (~9.87%), ^{87}Sr (~7.04%), and ^{88}Sr (~82.53%) (Faure and Powell, 1972; Knudson et al., 2010). Of the four isotopes only ^{87}Sr is radiogenic. This isotope is formed over time by the decay of radioactive rubidium (^{87}Rb) in the bedrock, which has a half-life of 4.88 x 10^{10} years (Faure, 1986; Knudson et al., 2004). As a result, the concentration of ^{87}Sr relative to other Sr isotopes in the environment is a result of a bedrocks' age and Rb content (Bentley, 2006; Faure, 1986). Sr enters the biosphere through uptake from the substrate by plants and is passed along the food chain into, for example, the tissues of animals and humans. The chemical behavior and similar atomic mass of Sr and calcium (Ca) allows Sr to substitute for Ca, in the cellular structures of plants or in the hydroxyapatite of both bone and tooth enamel (Ericson, 1985; Graustein, 1989; Nelson et al., 1986). In contrast to many commonly utilized light isotope systems, the isotopic composition of Sr does not change or fractionate appreciably during biological processes (Graustein, 1989). This is because the mass differences between the four Sr isotopes are relatively small (Elias et al., 1982; Faure and Powell, 1972; Graustein, 1989; Knudson et al., 2010). As a result, the ^{87}Sr/^{86}Sr values measured in flora and fauna depend on the age of the bedrock on which they sourced their nutrients.

Very old bedrock that has high Rb/Sr ratios will have the highest ^{87}Sr/^{86}Sr values today (Faure, 1986; Turekian and Kulp, 1956). Examples of geological deposits that have high Rb/Sr ratios include clay-rich rocks such as shale, or igneous rocks that have high silica content such as granite, with ^{87}Sr/^{86}Sr values up to 0.715 (Faure and Powell, 1972). On the other hand, geologically young rocks and sediments will have low Rb/Sr ratios and typically have ^{87}Sr/^{86}Sr less than 0.706 (e.g. Rogers and Hawkesworth, 1989). For marine environments, the isotopic composition is characterized by a global constant ^{87}Sr/^{86}Sr ratio of 0.7092 (Ericson, 1985; Veizer,

1989) and is often higher than what is found in freshwater (Ericson, 1985; Koch et al., 2007).

The $^{87}Sr/^{86}Sr$ values of the underlying bedrock of a particular region may not necessarily correspond to the composition of the bioavailable Sr that makes its way into local soils, bodies of water, plants and animals. Besides local bedrock, Sr can also be derived from atmospheric and surface sources, such as rainfall, rivers, sea-spray, wind-dust (Bentley, 2006; Crowley et al., 2017; Fenner and Frost, 2014; Frei and Price, 2012). Additionally, anthropogenic Sr contaminations can be introduced through fertilizers and even via dust, for example, from modern large scale construction sites (Bataille and Bowen, 2012; Bentley, 2006; Price et al., 2002; Willmes et al., 2018). As organisms consume local food and water, these various sources of Sr are mixed and incorporated into their tissues. To infer the biologically available $^{87}Sr/^{86}Sr$ values in an area, newer studies commonly use samples of uncontaminated environmental sources of local origin such as plants and small animals (Bentley, 2006; Sillen and Kavanagh, 1982; Valentine et al., 2008; Willmes et al., 2018), water (Crowley et al., 2017; Frei and Frei, 2013; Scaffidi and Knudson, 2020; Shand et al., 2009), and soil (Bentley, 2006; Willmes et al., 2018).

Additional detailed description of the use of $^{87}Sr/^{86}Sr$ isotope analysis and its applications in archaeological science appears in Chapter 5.

3.7 Ancient DNA

Characteristics of DNA

DNA or deoxyribonucleic acid is the hereditary material in humans and almost all other organisms (Jobling et al., 2013). Most DNA is located within cell nuclei (nuclear DNA. nDNA), but a small amount of DNA can also be found within mitochondria (mtDNA; discussed in more detail below). Nuclear DNA is a 46-chromosome (diploid) long structure that contains an individual's unique genetic code in which 23 chromosomes (haploid) are inherited from the mother and 23 from the father. The genetic information of all DNA is made up of four basic chemical bases; adenine (A), cytosine, (C), guanine (G) and thymine (T) (Jobling et al 2014). The general sequence of these bases forms the instructions for the entire genome. The haploid human genome is made up of 3.2 billion bases of DNA, however, genome size is variable between species. The sequence of the bases determines the information available for building and maintaining an organism.

Nuclear DNA is a double-stranded molecule, where each strand is composed of long sequences of the four nitrogenous bases. The bases on one strand of the DNA molecule (i.e. A, C, G, T) are joined with complementary bases on the other by hydrogen bonds, (A with T and C with G) forming unique base pairs. Each base is also attached to a sugar and a phosphate molecule. Together this combination is called a nucleotide. Nucleotides are arranged in two long strands that resemble a double helix structure. This double helix forms a ladder with the base pairs acting as the rungs.

Each strand of DNA has a beginning and an end, called 5' (five prime) and 3' (three prime) respectively. The two strands run in opposite directions to each other so that one runs 5' to 3' (strand) and one runs 3' to 5' (antisense strand). During DNA replication, the double helix structure of DNA is essentially "unzipped" by an enzyme called helicase, which breaks the hydrogen bonds holding the base pairs together. The separation of the two single strands of DNA creates a "Y" shape called a replication fork. The two separated strands then act as templates for making new strands of DNA. The 3' to 5' is the leading strand while the other 5' to 3' strand is the lagging strand and as a result of their different orientations, the two strands are replicated under different processes.

The leading and lagging strands of "unzipped" DNA experience DNA replication differently. On the leading strand, a short piece of RNA (a nucleic acid with most of the properties of DNA, except that it only has a single strand of bases and instead of the base thymine, RNA has a base called uracil (U) called a primer that binds to the end of the strand. This primer acts as the starting point for DNA synthesis. DNA polymerase (an enzyme involved in making new DNA molecules) then binds to the leading strand and moves along the strand, adding new complementary nucleotide bases to the strand in the 5' to 3' direction. This replication of the leading strand is continuous.

On the lagging strand, numerous RNA primers bind to various points along the strand. Chunks of DNA, called Okazaki fragments, are then added to the lagging strand also in the 5’ to 3’ direction. This type of replication is discontinuous because the Okazaki fragments will need to be joined later.

Once all of the bases are matched up on both strands, an enzyme called exonuclease strips away the primers. The gaps are then filled in by complimentary nucleotides. To make sure there are no mistakes in the new DNA sequence, the new strand is essentially “proofread”. Finally, an enzyme called DNA ligase seals up the sequence into two continuous double strands. Following replication, the new strands of DNA automatically wind into a double helix structure and the process is repeated.

Although most DNA is packaged in chromosomes within the one nucleus of a eukaryote cell, mitochondria also have a small amount of their own DNA. The mitochondrial genome is composed of double-stranded DNA with only 16,569 base pairs. In contrast to the linear chromosomal elements of nuclear DNA, the mitochondrial genome is circular in shape. In addition, one mitochondrion contains dozens of copies of its mitochondrial genome. Therefore, any given cell can contain several thousand copies of its mitochondrial genome, whereas only one copy of its nuclear genome.

In addition to the higher copy rate of the mitochondrial genome in each cell, the mt-genome experiences an about 100-fold higher mutation rate than the nuclear genome. This leads to a heterogeneous population of mitochondrial DNA within the same cell, and even within the same mitochondrion. When a cell divides, its mitochondria are partitioned between two daughter cells. However, the process of mitochondrial segregation occurs randomly and is much less organized than DNA replication in nuclear DNA. As a result, daughter cells receive similar, but not identical, copies of their mtDNA.

Nuclear DNA vs. Mitochondria DNA modes of inheritance

The human nuclear genome is divided into 46 chromosomes or 23 pairs, with one of each pair inherited from each parent. The autosomes (22 chromosomes) are identical between sexes. The remaining two chromosomes (sex chromosomes) differ between biologically defined sexes (i.e. XX and XY). There are two primary types of cells; germ cells and somatic cells. Germ cells produce gametes (sex cells), through meiosis and contain one set of chromosomes. Somatic cells, found in blood, connective tissue, bone, skin and internal organs, are produced through mitosis.

Mitosis operates on somatic tissues in which each daughter cell contains the same genetic material as the parental cell. Mitosis is a critical process, allowing a single cell fertilized egg to develop and grow through an enormous amount of mitotic cell division. Mitosis replication has great influence over the development of diseases such as cancer. However, in evolutionary terms the most important class of cell division is in the germ line where gametes are produced. These gametes enable the passage of genetic information to the next generation. Mitotic mutations are not inherited and will exist only as long as the individual who carries them, whereas any mutations that occur in meiosis can be passed on.

A gamete is haploid, containing only one copy of the genome. These cells undergo cellular replication through meiosis, in the germ line. The genetic differences between gametes are the result of two distinct processes. First, the independent assortment of chromosomes in which the reduction from diploidy to haploidy necessitates the choice between the two sets of chromosomal pairs, leads to differences between gametes. The second process is recombination, during which paternal and maternal chromosomal pairs align and exchange segments (also known as cross-over). This process is reciprocal, and there is no net loss of genetic information. Assortment and recombination ensure that any one gamete produced by either sex is genetically different from any other.

The majority of the human genome is inherited from both parents and undergoes genetic reshuffling each generation through recombination. However, there are two segments of DNA that are atypical, inherited from one parent only and are not subject to total recombination events; the Y-chromosome and mtDNA. The Y-chromosome is male specific, passed directly from father to son, and thus, provides information about patrilineal population dynamics (Fehren-Schmitz et al, 2010). mtDNA in humans is inherited through the maternal line. Due to the high mutation rates associated with mtDNA, significant variability exits in mtDNA sequences among unrelated individuals, however, mtDNA of maternally related individuals is more similar.

Differences between Y-chromosomal, autosomal, and mtDNA allows geneticists to understand many aspects of population health, history, and interaction. For example, modern genetic screening companies like “Ancestry.com” and “23 and Me”, benefit from the undamaged and high complexity characteristics of modern

DNA and especially nuDNA. These companies focus on regions of the genome known to be associated with heath conditions, ancestry, and genetic traits.

Characteristics of ancient DNA

Unlike modern DNA analyses, the study of ancient DNA from a methodological perspective faces two major technical limitations not encountered in modern DNA studies; the poor preservation of endogenous DNA and the presence of contaminant exogenous DNA. With the advent of new sequencing technologies and extraction protocols, the field of ancient DNA (aDNA) has begun to accomplish what was previously thought of as impossible. This includes genome mapping of extinct organisms such as *Homo neanderthalensis* (Green et al., 2010; Paixão-Côrtes et al., 2012), and distinguishing endogenous from contaminant DNA in archaic *Homo sapiens* specimens (Krause et al., 2010; Rizzi et al., 2012).

The post-mortem degradation of DNA contributes to the poor preservation of aDNA. In metabolically active tissues, damage to the DNA molecules is rapidly and efficiently repaired (Gilbert et al., 2005a; Gilbert et al., 2005b; Lindahl, 1993; Willerslev and Cooper, 2005). By contrast, DNA is no longer actively repaired in inactive or dead cells resulting in the accrual of permanent damage over time. Consequently, most ancient specimens do not contain any amplifiable endogenous DNA and those that do possess only fragments in the 100-500 bp size range (Handt et al., 1994; Handt et al., 1996; Willerslev and Cooper, 2005). Early research showed that post-mortem DNA decay was characterized by strand breaks, baseless sites, miscoding lesions, and crosslinks. These processes result in sequencing artifacts and the preferential amplification of undamaged contaminant DNA (Lindahl, 1993; Willerslev and Cooper, 2005).

Poinar and colleagues (1996) state that environmental conditions have more influence on DNA preservation than time (Colson et al., 1997; Höss et al., 1996) and conclude that there is no general correlation between the age of the sample and the preservation of DNA (Herrmann and Henke, 1999). For example, constant low temperatures can play a central role in the longevity of aDNA molecules. The oldest authenticated aDNA reports are all from permafrost settings, including greater than 50kyr-old mammoth mtDNA (Höss et al 1994; Willerslev and Cooper 2005). By contrast, samples obtained in hot/humid environments tend to exhibit higher damage rates than those from low temperature environments.

Contamination due to the presence of exogenous DNA or the detection of several haplotypes for a single individual is the second limiting factor of aDNA analyses. The implications of this problem have led to the development of a set of guidelines for authentication of ancient DNA results (Poinar and Cooper 2000). These guidelines include the use of dedicated DNA laboratories (clean labs), biochemical preservation tests, multiple negative controls during extraction and amplification, quantification of target DNA, cloning and sequencing of polymerase chain reaction (PCR) products, screening for human DNA in associated nonhuman remains, control of amplicon length, and reproducibility of results, both in-house and in a second laboratory (Fehren-Schmitz et al., 2010; Gilbert et al., 2005a; Handt et al., 1994;

Handt et al., 1996; Hofreiter et al., 2001; Hofreiter et al., 2002; Kwok and Higuchi, 1989; Malmström et al., 2005; Pääbo, 1989; Pääbo et al., 2004; Poinar and Cooper, 2000).

However, even when these guidelines are followed authenticated results have/can be questioned. When potential modern contaminants share haplotypes with the ancient material, it is difficult to conclusively authenticate the sequence (Malmström et al, 2005). For example, laboratory technicians may share a common haplogroup with the ancient sample thus making authentication difficult. The discussion of contamination is further complicated by studies that detect contamination in aDNA extracts without showing contamination in the accompanying negative controls (Kolman and Tuross, 2000). This phenomenon has been explained by the so-called carrier effect, where low concentrations of contaminant DNA in PCR and extraction blanks are rendered PCR un-amplifiable through adherence to plastic ware and equipment (Handt et al., 1994; Malmström et al., 2005). Alternatively, contamination of bone samples by modern DNA, rather than laboratory reagents as the cause of unidentifiable contaminant DNA, has also been purposed (Kolman and Tuross, 2000; Richards et al., 1995).

3.8 Conclusions

Recent methodological discoveries in both the field of stable isotope and ancient DNA analyses allow researchers to study past populations in unprecedented detail. The combination of stable isotope and ancient DNA analyses provides a unique opportunity to study past cultural processes that had both long-lasting effects on the genetic relationships between individuals, as well as short term choices contained within the life history of an individual.

This dissertation project primarily focuses on the use of light-stable isotope analysis for dietary reconstruction and heavy-stable isotope studies to examine patterns in past human mobility. The use of these isotope systems provides an initial step in understanding human life history and paleodietary adaptations within the ancient Andean highlands. While not discussed in the main case-studies of this dissertation, a significant portion of my research goals include the incorporation of aDNA analysis to create a more holistic view of life and interaction within the Andean Highlands. During the course of my dissertation research I processed a large number of samples for aDNA, the results of which have not yet been analyzed. Future directions for this component of my research will be discussed in chapter 7.

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CHAPTER 4

Maize and Dietary Change in Early Peruvian Civilization: Isotopic Evidence from the Late Preceramic Period/Initial Period Site of La Galgada, Peru

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Note: Published in the Journal of Archaeological Science: Reports, 2020. Permission to include this article as a chapter of this dissertation was granted by all co-authors (see signed permission letters at the end of this chapter)

Reference:
Washburn, E., Nesbitt, J., Burger, R., Tomasto-Cagigao, E., Oelze, V.M., Fehren-Schmitz, L., 2020. Maize and dietary change in early Peruvian civilization: Isotopic evidence from the Late Preceramic Period/Initial Period site of La Galgada, Peru, Journal of Archaeological Science: Reports 31, 102309.

Abstract

The Late Preceramic Period (3000-1700 B.C.E.) and Initial Period (1700-800 B.C.E.) in Peru was a time of emergent social complexity as illustrated by the construction of ceremonial architecture and permanent settlements. A long-standing debate centers on the nature of the subsistence economies that supported this incipient complexity. Though some scholars consider maize to have been an agricultural staple at this time, a growing body of archaeological research indicates that the use of maize spread irregularly throughout Peru and did not become a dietary staple until sometime after c. 800 cal B.C.E. Using stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$) of human bone and dentine, together with radiocarbon dating, this study estimates dietary composition, as well as changing subsistence strategies among 32 individuals interred within the ceremonial center of La Galgada (2300-1300 cal B.C.E.). Our data suggests that maize was not a dietary staple in either the Late Preceramic or the Initial (1700-800 cal B.C.E.) Period occupations at La Galgada. Instead the modeled diet (SIAR Mixing Model) suggests a continued reliance on locally available food sources (i.e. primarily C_3, legumes and grazing fauna). This finding combined with archaeological evidence indicates that diet remained relatively similar during the site's occupation. Three radiocarbon dates generated for this study also indicate the re-use of La Galgada as a cemetery during the Late Intermediate Period (LIP) (1150-1450 cal C.E.). Diet during the LIP exhibits a significant change, with a decrease in the proportion of C_3 and legumes and an increase in the proportion of meat. This study highlights the utility of mixing models to reconstruct past human diet, allowing for a more comprehensive understanding of potential differences in the proportions of food types over time.

Key Words: Stable Isotope Ratios, Maize, Peru, Late Preceramic Period, Initial Period, Late Intermediate Period, Dietary Mixing Mod

4.1 Introduction

The Late Preceramic Period (c. 3000-1700 cal B.C.E.) is of crucial importance to understanding the development of sociopolitical complexity in the Central Andes. Beginning in the early half of the third millennium B.C.E., different cultures living along the Peruvian coast and adjacent highlands initiated the construction of early traditions of monumental public architecture, which were associated with permanent settlements (Burger 1992; Pozorski and Pozorski 2018a; Quilter 1991; Solis et al. 2001). This pattern continued into the Initial period (1700-800 cal B.C.E.), with a significant proliferation of monumental centers, as well as the introduction of pottery technology (Burger 1992; Pozorski and Pozorski 2018a). Furthermore, the Late Preceramic Period and early part of the Initial Period also underwent significant changes to the subsistence economy, with a growing reliance on cultigens like squash (Cucurbitaceae), beans (Fabaceae), manioc (*Manihot esculenta*), potatoes (*Solanum tuberosum*), and quinoa (*Chenopodium quinoa*), as well as wild game (Beresford-Jones et al. 2018; Caramanica et al. 2018; Coutts et al. 2011; Dillehay et al. 2005**,** 2007; Duncan et al. 2009; Moseley 1975; Nesbitt 2016; Paredes 2018; Perry et al. 2006; Pozorski 1979, 1983; Pozorski and Pozorski 1979; Quilter et al. 1991; Rumold and Aldenderfer 2016; Weir et al. 1988).

Nevertheless, some scholars have argued that one specific cultigen – maize (*Zea mays*) – played an instrumental role in stimulating the development of early Central Andean complexity (e.g. Bonavia 2008; Bonavia and Grobman 1989, Haas et al. 2013; Kidder et al 1963; Norr 1995; Wilson 1981). However, the growing archaeological record for the Late Preceramic Period and Initial Period indicate that while consumed, maize was not an important crop in Peru until after c. 800 cal B.C.E. (Blake 2015; Staller et al. 2006; Burger 2012; Burger and Van der Merwe 1990; Pezo-Lanfranco et al. 2015; Pozorski and Pozorski 1979, 2006; Seki and Yoneda 2005; Shady 2006; Tykot et al. 2006). The use of stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$) has the potential to elucidate these potential changes in diet, as well as determine the specific contribution of different foods, including maize, within an individual's diet.

In this article we evaluate the nature of Late Preceramic Period and Initial Period diet based on isotope analysis of human remains recovered from the site of La Galgada. Occupied between c. 2300 and 1300 cal B.C.E., La Galgada provides a unique opportunity to evaluate the transition between the Late Preceramic and Initial Periods and the accompanying changes in individual life-histories and diet; it is the only Late Preceramic ceremonial center in the Andean highlands from which large numbers of human burials have been documented (Grieder and Bueno Mendoza 1985; 1988). This study presents carbon and nitrogen stable isotope data ($\delta^{13}C$ and $\delta^{15}N$) measured in human skeletal remains (n=32) found at La Galgada alongside new radiocarbon dates of this material, in order to understand past human diet and the degree of dietary variation and change through time. The aim of this study is to determine if there are detectable differences in diet present in bone/dentine isotope ratios throughout the occupation of the site. By analyzing burial contexts that date to the Late Preceramic and Initial Periods, this study addresses questions regarding the timing of subsistence change, as well as the importance of maize as a food source in the Andean highlands during this crucial period of cultural development.

4.2 Background

4.2.1 Changes in subsistence practices through time

During the Late Preceramic Period, the Peruvian highlands transformed into a highly complex cultural landscape. For a millennium before the introduction of pottery, highland populations built monumental public architecture and permanent settlements, developed irrigation agriculture, created fine textiles, and worked in bone, shell, stone and basketry (Burger 1992; Quilter 1991).

Major highland centers are found in a diverse range of environmental zones. Examples of Late Preceramic Period highland centers include Kotosh (2000 masl) (Izumi and Sono 1963; Izumi and Terada 1972), in the Huallaga Drainage, Piruru (3800 masl) in the Alto Marañon (Bonnier 1997), Huaricoto (2500 masl) (Burger and Salazar-Burger 1980, 1985, 1986), Hualcayán (3150 masl) (Bria 2017), and Tumshucaico (2300 masl) (Bueno Mendoza 2004) in the Callejón de Huaylas, and La Galgada (1100 masl) (Grieder and Bueno Mendoza 1985; 1988) in the Tablachaca River Valley (Figure 4.1). Despite the distances separating them, these Late Preceramic religious centers share key architectural similarities referred to as the Kotosh Religious Tradition (Burger and Salazar 1980)**.** While much is known about the architecture and religious practices of these highland peoples, less visible aspects of individual life histories including subsistence practices and the varied reliance on available food resources remains unclear.

Late Preceramic Period coastal and highland communities of the north-central Andes relied on mixed economies, including domesticated cultivars that were supplemented by hunting and fishing (e.g. Burger and Van der Merwe 1990; Quilter et al. 1991). Plant domestication in coastal communities began by c. 8500 years ago with crops like squash, peanuts, beans, manioc and chili peppers (Dillehay et al. 2007; Pearsall 2008; Perry et al. 2007; Piperno 2011; Piperno and Dillehay 2008). Maize was present on the coast by at least 6500BCE (Grobman et al. 2012) and has been found in the form of macrobotanical and microbotanical remains at Late Preceramic centers on the coast (Haas and Creamer 2004, 2005; Haas et al. 2013; Shady 2006). In the highlands, the use of cultigens also begins relatively early, with an emphasis on species that are well adapted to high altitude habitats like potato, oca (*Oxalis tuberosa*), diverse leguminous plants, and quinoa (Burger and Van der Merwe 1990; Rumold and Aldenderfer 2016). Botanical findings at Guitarrero Cave (Lynch 1980) and Hualcayán (Bria 2017: 521), and isotopic studies from the Callejón de Huaylas in the north-central highlands (Burger and Van der Merwe 1990) indicate that maize was also present in the highlands around this time. There is also evidence of maize during the Late Preceramic Period in the south-central highlands (Perry et al. 2006). However, the significance of maize as a dietary resource remains unclear. At this time, animal proteins were likely derived largely from deer, but camelids and small game would have been additional food sources (Burger 1992; Miller and

Burger 1995; Miller 1984; Sawyer 1985; Shimada 1982; Uzawa 2010; Wing 1972, 1978).

In the subsequent Initial Period, highlands subsistence patterns largely depended on rainfall farming supplemented by hunting, with the range of available cultigens varying by ecological zone. There are, however, examples of irrigation in the middle and upper portions coastal valleys at sites such as La Galgada (Grieder 1981; Grieder et al. 1988). In the northern highlands, valley slopes may have been used to grow maize and beans, while lower elevation valley floors were co-opted to grow plants like manioc that can be cultivated at lower altitudes (Burger and Van der Merwe 1990).

4.2.2 The site of La Galgada

La Galgada is located near the floor of the middle Tablachaca Valley of north-central Peru (Figure 4.1). At an elevation of 1,100 masl, La Galgada is positioned along the western slope of the Andes and is approximately 80 km east of the Pacific shoreline. The site is situated in the *yunga* (500-2,300 masl) production zone. This zone is arid and warm, and agriculture is only feasible through irrigation. Despite these challenges, the western *yunga* is highly productive and its warm climate permits the cultivation of tropical and low elevation crops (Onuki 1985).

La Galgada was founded in the mid-to-late third millennium B.C.E. and consists of two large mounds (Grieder et al. 1988). Excavations of the larger of these two mounds revealed a sequence of ceremonial chambers, each with a central fire pit

(Burger, 1992; Grieder et al., 1988) following architectural conventions of what is known as the Kotosh Religious Tradition (Burger and Salazar Burger 1980). The excavations at the site indicate that it was occupied into the Initial Period when it was abandoned around 1300 B.C.E.

Among sites of the Kotosh Religious Tradition, La Galgada is unique because of the high quantity of Late Preceramic and Initial Period tombs (Grieder et al. 1988). One type of tomb consisted of firepit chambers that were reutilized as burials, while the other type consisted of interments within galleries. Tombs generally contained multiple individuals buried within them. These tombs consisted of the commingled remains of both males and females and the majority were either under 4 or over 40 years of age (see below). Many of the tombs contain elaborate grave goods including bone pins, turquoise, cotton textiles and *Spondylus* shell. Based on the presence of grave goods, the individuals buried at La Galgada may have been high status members of the community (Grieder et al. 1988).

Because of its dry environment, plant remains at La Galgada were well preserved. Botanical remains recovered from the site suggests that agricultural efforts were focused on crops such as lima beans (*Phaseolus lunatus)*, peanuts (*Arachis hypogea*), avocados (*Persea americana*), and other food plants, as well as cotton (*Gossypium* sp.) (Grieder and Mendoza, 1981; Grieder et al., 1988). Evidence for the use of maize derives from a single cob, recovered from context D11- A/D-4/7 Floor 3, an apparently late level of occupation (Smith 1988).

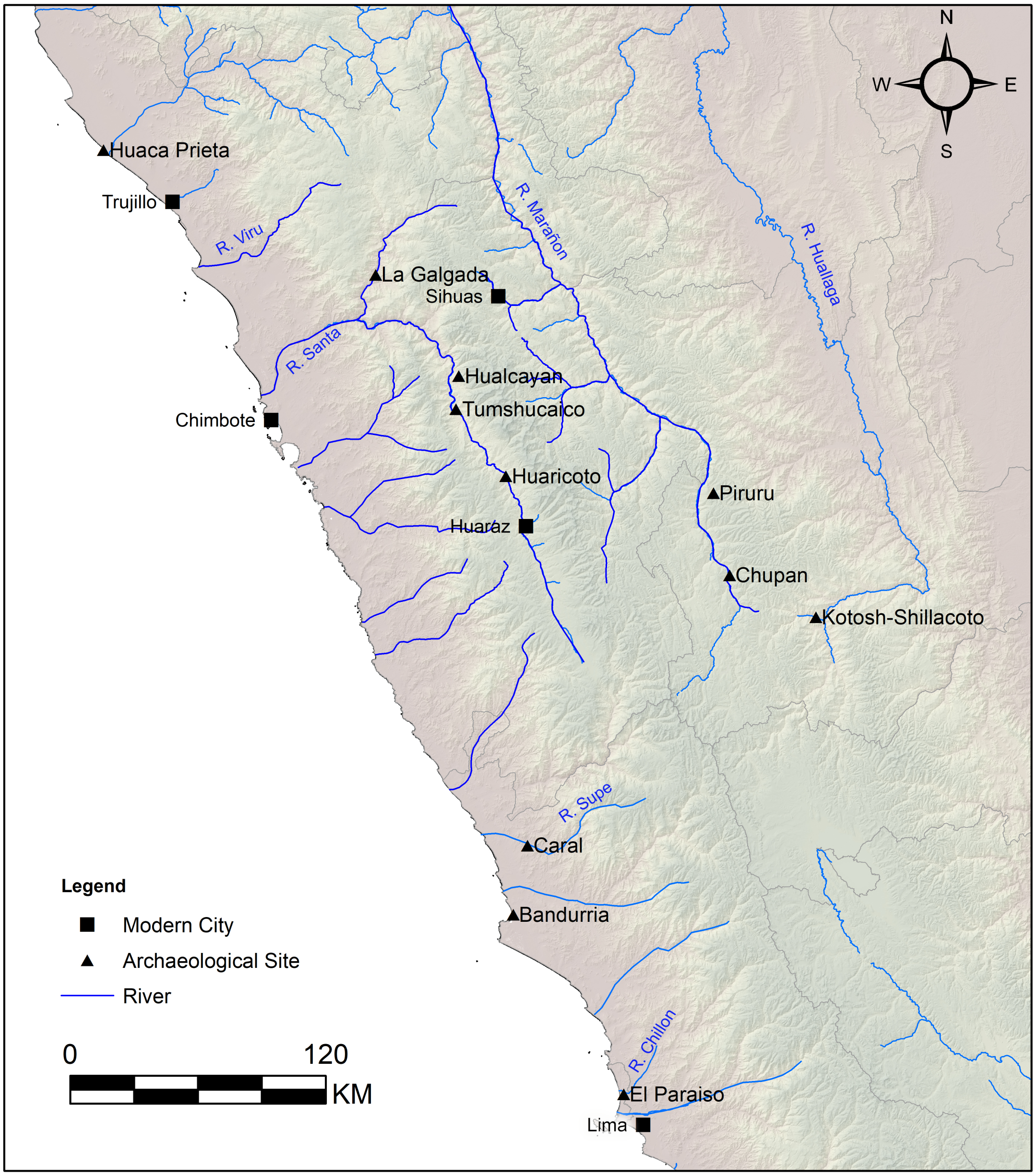

Figure 4.1: Map of Peru with the location of La Galgada and other sites mentioned in the text.

4.2.3 Reconstructing past diets through stable isotope analysis

This study utilizes the analysis of stable isotope ratios of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) in human and faunal remains to reconstruct the diets of the past populations interred at the site of La Galgada. Based on previous research conducted at La Galgada, the large number of macrobotanical remains analyzed and the lack of faunal remains suggest that the diets of Late Preceramic and Initial Period individuals should exhibit $\delta^{13}C$ and $\delta^{15}N$ values that reflect a primarily plant based (C_3 and legumes) diet with limited amounts of terrestrial or marine and/or freshwater based protein.

The fundamental variation in values of $\delta^{13}C$ in terrestrial food webs stems from differences in the photosynthetic pathways of plants (Finucane et al. 2006; Schoeninger and Moore 1992). The majority of plants, including those in the Central Andes, utilize the Calvin Cycle (C_3) and have an average $\delta^{13}C$ value of -26.5‰ (Tieszen 1993; Van der Merwe and Medina 1989). However, many grasses native to hot, arid environments, including domesticates such as maize, millet, amaranthus (kiwicha) and sugarcane rely on the Hatch-Slack pathway (C_4) and can be identified by their substantially higher $\delta^{13}C$ values, averaging around -12.5‰ (Finucane et al. 2006; Van der Merwe and Medina 1989). Plants utilizing the third photosynthetic pathway (CAM), such as succulents (i.e. prickly pears) have intermediate $\delta^{13}C$ values.

Compared to C_3 plants, wild C_4 plants are rare in the Andes (Powell and Still 2009). Therefore, any $\delta^{13}C$ value indicating a reliance on C_4 plants is commonly used to suggest the consumption of maize (Burger and Van der Merwe 1990; D'Altroy 2001; D'Altroy and Schreiber 2004; Finucane et al. 2006, 2007, 2009; Goldstein 2003; Hastorf 1991; Kellner and Schoeninger 2008**;** Slovak et al. 2009; Slovak and Paytan 2011; Tung et al. 2016; Tung and Knudson 2018; Tykot 2006; Wilson et al.

2007). However, higher $\delta^{13}C$ values might also suggest a reliance on animals that consumed maize or other C_4 grasses (Cadwallader et al. 2012), a distinction not commonly addressed. In addition, the distribution of wild C_4 grasses throughout the Andes may be underrepresented in the literature, especially in dietary studies which focus primarily on those plants that are edible by humans.

Analysis of $\delta^{15}N$ values provides information on past diets by discriminating between non-leguminous plants, leguminous (N-fixing) plants and higher tropic level foods, such as animal protein (Schoeninger and DeNiro 1984**;** Walker and DeNiro 1986**)**. With each step up the food chain there is a tropic level ~3‰ increase in the $\delta^{15}N$ values (Schoeninger and DeNiro 1984). This tropic level effect is particularly evident in the highly complex food webs typical of aquatic habitats, such as in marine or freshwater fish (Ambrose and Norr 1993). Due to the absence of fish bones and mollusk remains in the archaeological assemblage at La Galgada, the presence of $\delta^{15}N$ values suggesting a heavy reliance on marine resources is unlikely.

We use stable isotope analysis to assess the contributions of C_3, C_4, and leguminous plants, as well as wild and domesticated animals in the diets of individuals interred at La Galgada. In addition, we explore whether evidence of a gradual transition to maize agriculture is reflected in the diet from the Late Preceramic to Initial Period individuals.

4.3 Materials

At La Galgada, 16 tombs were excavated by Grieder and colleagues (Grieder et al. 1988). Nine of these tombs contained multiple individuals (~3-27 individuals) (Table 4.1**)**. Bone and teeth (M_2 and M_3) were sampled from 32 individuals (distributed between the nine tombs in which multiple individuals were identified) at the *Museo Nacional de Arqueología, Antropología, e Historia del Perú*, Lima, where the archaeological materials from La Galgada are currently curated. The majority of tombs were looted and in most cases the burials were not completely intact and/or commingled, leaving analysis of skeletal remains difficult (Grieder et al. 1988).

Table 4.1 List of tombs from La Galgada and number of sampled burials (Grieder et al. 1988)

Tomb	Chamber	Gallery	MNI Identified	No. of individuals Sampled for this project
F12-B2	X		3	1
I11-B8	X		?	
G12-I2	X		4	1
I12-C5	X		?	
C10-E10		X	3	3
C11-F5	X		14	6
C11-I3	X		?	
H12-C2		X	?	
I12-G4		X	?	
C12-D1		X	10-12	6
D11-C3	X		4	4
G11-I5		X	1	
C11-E8	X		3	2
C10-I10		X	4	3
I11-J2		X	?	
E11-J7		X	27	6

Isotope data from possible dietary resources was compiled from the available literature (DeNiro and Hastorf 1985; Finucane et al. 2006; Turner et al. 2010) and dietary data was limited to food types found in highland sites with similar ecological conditions as at La Galgada (Table A4.1). In our model, only modern plant samples were included from DeNiro and colleagues (1985) and as a result, are likely exposed to at least minimal amounts of either manuring or modern fertilizer. The effect of manuring on plants can result in substantial changes in $\delta^{15}N$ values, while modern fertilizer can either raise or lower $\delta^{15}N$ values (DeNiro and Hastorf 1985; Szpak et al. 2012). There are, however, no statistical or analytical means of detecting this in our mixing model. As a result, we consider the plants included in our mixing model to represent different levels of manuring and fertilization.

In addition, as there has been no extensive isotopic study of wild deer found throughout the Andes, four white-tailed deer (*Odocoileus virginianus)* found at the highland site of Canchas Uckro (c. 1100-800 cal B.C.E.), approximately 120km south of La Galgada, were analyzed and included in this study (Figure 4.1, Table A4.2).

Finucane and colleagues (2006) report two distinct groups of camelids, indicating the practice of two forms of animal husbandry during the Middle Horizon at Conchopata (600-1000 C.E.); rangestock grazing on puna pasture characterized by C_3 vegetation, and the feeding of C_4 plants (maize). For our dietary mixing model, camelid $\delta^{13}C$ and $\delta^{15}N$ values were split into two groups depending on their carbon isotope value (i.e. Group 1: C_3 plant grazers; Group 2: foddered). Guinea pigs have diets that reflect available "table scraps" and would therefore share similar isotope values with the humans themselves (Finucane et al. 2006) and for this reason guinea pig isotope values were combined into one group (Figure 4.2).

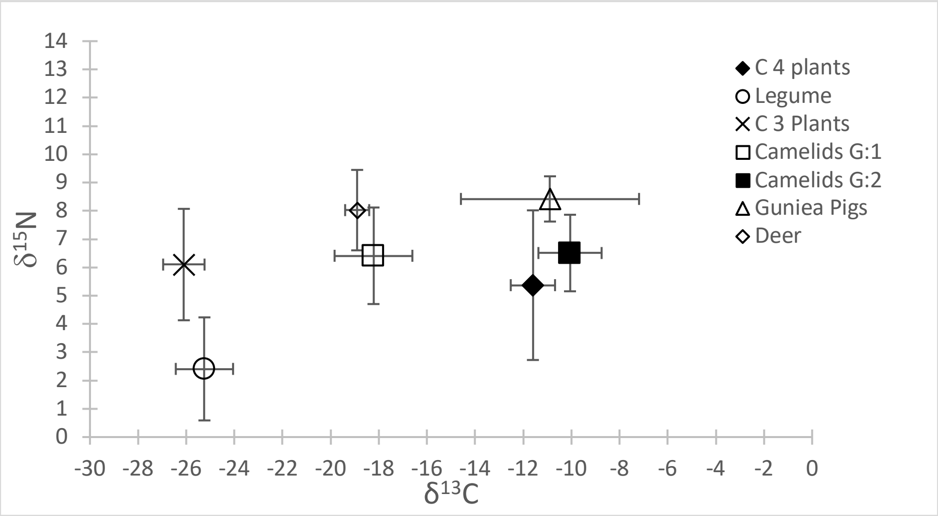

Figure 4.2: Dietary source data compiled from DeNiro and Hastorf 1985; Finucane et al. 2006; Turner et al. 2010. Deer excavated from archaeological site of Canchas Uckro and analyzed for this project.

4.4 Methods

4.4.1 Radiocarbon dates

There are 13 radiocarbon dates from the original excavations at La Galgada. Radiocarbon measurements were obtained from charcoal/wood samples (n=12) and cloth (n=1) from chamber and gallery floors. These dates span both the Late Preceramic and Initial Periods (Grieder et al. 1988). However, there are problems with the dates as many of the measurements had large standard errors, which produced calibrated dates with wide ranges that span several centuries (e.g. TX-4450) (Table 3). Furthermore, Grieder and colleagues did not run any radiocarbon measurements on the bone of the human burials themselves.

In the present study, we directly dated at least one individual from nine of the La Galgada tombs (Table 3). Nine bone samples were sent to the UC Irvine W. M. Keck Carbon Cycle Accelerator Mass Spectrometry Laboratory and the Curt Engelhorn-Zentrum Archaeometrie Laboratory in Manheim Germany for AMS dating. The new radiocarbon dates from this study together with those published by Grieder (1988) were calibrated using the Southern Hemisphere Calibration Curve (SHCal13) (Hogg et al. 2013) on OxCal v4.3.2. Though there is some disagreement about whether the International Calibration Curve (IntCal13), SHCal13, or a mixed curve is most appropriate to use in highland Peru, a recent study suggests that the best curve for this part of Peru is probably SHCal13 (Marsh et al. 2018). Furthermore, differences between the IntCal13, SHCal13, and mixed curves produce negligible differences (e.g. Nesbitt et al. 2020).

4.4.2 Stable Isotope Analysis

Prior to the start of this project, human bone and tooth samples were pulverized for aDNA extraction (results not presented here). With the remaining powder, we followed a modified protocol by Ambrose (1990) to extract collagen. We immersed the bone/tooth powder (0.5 to 0.8g) in 1.5ml 0.5M HCl for a duration of 24 hours to fully demineralize and remove the hydroxyapatite fraction. The demineralized powder was rinsed with dH_2O three subsequent times, with centrifugation following each rinse. Samples were then treated in 1.5ml 0.125M NaOH for 24 hours to remove humic contaminants. Samples were again rinsed with

dH_2O (x3), immersed in 1.5ml pH≈3 dH_2O, and placed in an oven at 70°C for 48 hours to solubilize the collagen. The liquid fraction was then removed and transferred to a clean 1.5ml Eppendorf tube. Samples were filtered using eeze™ filters (60-90μm) to remove remaining solid particles, and the liquid fraction was freeze-dried.

The four deer samples were prepared following a modified protocol by Richards and Hedges (1999). Samples were demineralized using 0.5M HCL, rinsed 3x with dH_2O. pH≈3 water was added to each sample and samples were placed in heater blocks at 70°C for 48 hours. Following collagen solubilization, remaining particles were filtered using eeze™ filters (60-90μm). Samples were then subjected to ultracentrifugation using AMICON Ultra-4 filters with a 30 kDa cutoff and freeze dried. Only the large fraction of collagen (i.e. >30kDa) was analyzed.

Collagen samples were weighed, encapsulated in tin, and analyzed for carbon (C) and nitrogen (N) stable isotope ratios by the University of California Santa Cruz Stable Isotope Laboratory using a C.E. Instruments NC2500 elemental analyzer coupled to a Thermo Finnigan DELTAplus XP isotope ratio mass spectrometer via a Thermo-Finnagan ConFlo III. Duplicates were performed on every 5th sample to substantiate measurement accuracy. All measurements have been corrected to VPDB (Vienna PeeDee Belemnite) for $\delta^{13}C$ and AIR for $\delta^{15}N$ against an in-house gelatin standard reference material (PUGEL), which is extensively calibrated against international reference materials. Measurements were corrected for size and blank-mixing effects and drift effects. An externally calibrated Acetanilide standard reference material purchased from Dr. Arndt Schimmelmann of Indiana University is measured 'as sample' for independent quality control. Typical reproducibility of replicates is significantly better than 0.1‰ for $\delta^{13}C$ and 0.2‰ for $\delta^{15}N$.

4.4.3 Statistical Data Analyses

We tested the differences in $\delta^{13}C$ and $\delta^{15}N$ values across archaeological time periods, in individuals from the Late Preceramic Period, the Initial Period and the LIP burials (n=3 time periods) using one-way analyses of variance (ANOVA) in R (R Core Team 2013) with significance levels set to 0.05. Significant ANOVA results were followed up using a Tukey-Kramer post-hoc test to identify significant differences between time periods. This post-hoc test, acts as a t-test but corrects for the increase in type 1 errors caused by preforming multiple t-tests.

Relative contributions of potential dietary sources were determined using the SIAR v4 (Stable Isotope Analysis in R) package in R (Parnell et al. 2010). SIAR provides a mixing model for estimating proportional contribution of different possible food sources in a consumer's diet (Parnell et al., 2010; Koch and Phillips 2002; Phillips and Koch 2002).

Each dietary source (i.e. C_4, C_3, legumes, camelids (Group 1 and Group 2), guinea pigs and deer) was condensed into an average $\delta^{13}C$ and $\delta^{15}N$ value ($\pm 1\sigma$) and used as the source dietary input for the model (Table 4.2).

Table 4.2: Average $\delta^{13}C$ and $\delta^{15}N$ values for the different dietary source used in the SIAR mixing models in this study (data compiled from DeNiro and Hastorf 1985; Finucane et al. 2006; Turner et al. 2010).

Source	**Mean $\delta^{13}C$ (‰)**	**1σ**	**Mean $\delta^{15}N$ (‰)**	**1σ**
C_4	-11.4	0.5	5.3	2. 6
Legumes	-25.3	1.2	2.4	1.8
C_3	-26.0	0.9	4.6	2.1
Camelids -Group 1	-18.2	1.6	6.4	1.7
Camelids - Group 2	-10.1	1.3	6.5	1.4
Guinea pig	-10.9	3.7	8.4	0.8
White-tailed Deer	-18.9	0.3	8.0	1.4

4.5 Results

4. 5.1 Radiocarbon Dates

The 9 new radiocarbon dates, along with the previously published dates are presented in Table 3. Six of the radiocarbon dates fall into either the Late Preceramic (n=4) or Initial Periods (n=2) and generally correspond with the absolute dates from the original excavations at La Galgada (Figure 4.3).

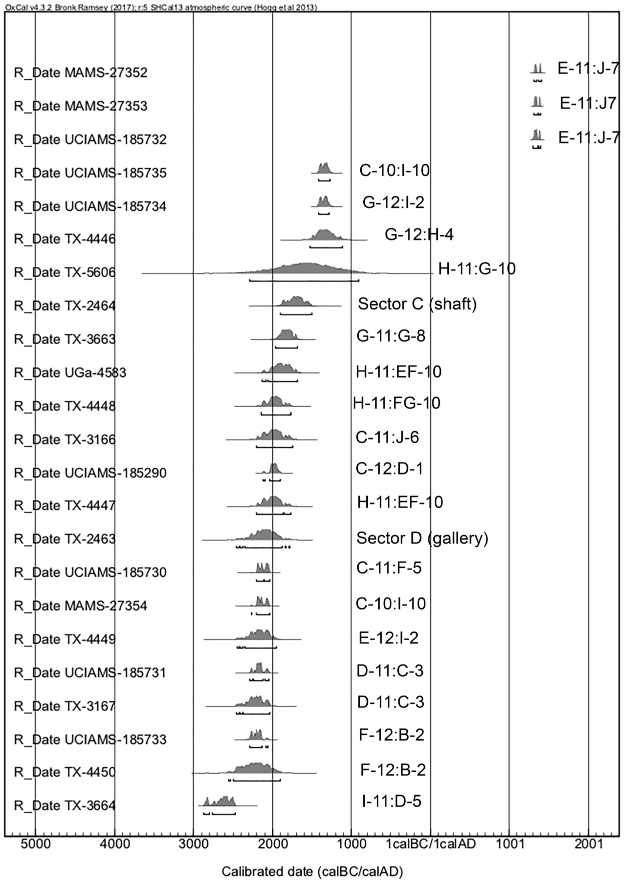

Figure 4.3: Calibrated radiocarbon dates from La Galgada. Radiocarbon dates were calibrated with OxCal 4.3.2 with the SHCal13 calibration curve (Hogg et al. 2013).

Surprisingly, three radiocarbon measurements from three different individuals found in gallery tomb E-11:J-7 are much later and produce dates of c. 1300-1400 C.E., which significantly postdates the Late Preceramic and Initial Periods. While these dates are much later than expected, they are internally consistent with one another, suggesting that these burials were deposited much later. Here it should be pointed out that in the original excavation report, Grieder and colleagues considered E-11:J-7 to be the latest tomb in their relative sequence. The building is described as anomalous and the authors describe this tomb as "an independent building" (Grieder et al. 1988: 62, 202) that had masonry styles that were distinct from other tombs at the site. This tomb was also significantly larger, containing at least 27 individuals. Burying this quantity of individuals in a single burial is reminiscent of mortuary practices characteristic of the Late Intermediate Period in the Peruvian highlands (Isbell 1997). These dates suggest that at least one of the tombs at La Galgada was reutilized long after the site was initially abandoned. This pattern of early monuments being reutilized by much later cultures for burials is a common practice throughout the Andes (e.g. Pozorski and Pozorski 2018b) but has not been previously identified at La Galgada

Table 4.3: All Radiocarbon Dates for La Galgada

Lab. number	Material	Tomb Context	C^{14} (BP)	SHCal13 (68.2%)	SHCal13 (95.4%)
MAMS-27353	Human bone	E-11:J-7; Gallery	648±15	AD 1320(55.9%)1350 1386(12.3%)1394	AD 1314(71.8%)1359 1380(23.6%)1400
MAMS-27352	Human bone	E-11:J-7; Gallery	629±20	AD 1324(44.4%)1345 1389(23.8%)1400	AD 1316(58.9%)1355 1381(36.5%)1409
UCIAMS-185732	Human bone	E-11:J-7; Gallery	655±20	AD 1319(57.1%)1351 1385(11.1%)1391	AD 1301(71.8%)1365 1375(23.6%)1400
UCIAMS-185735	Human bone	C-10:E-10	3125±15	1402(22.5%)1374 BC 1356(45.7%)1301	1416-1271 BC
UCIAMS-185734	Human bone	G-12:I-2; Chamber	3130±15	1407(26.1%)1375 BC 1351(42.1%)1303	1422-1277 BC
TX-4446	Burnt wood	G-12:H-4, Floor 8	3130±80	1436-1230 BC	1530-1110 BC
TX-5606	Cloth	H-11:G-10	3320±270	1917-1224 BC	2292-1901BC
TX-2464	Wood	Sector C shaft	3440±80	1873(6.9%)1844 BC 1814(2.9%)1801 1778(57.3%)1611 1571(1.0%)1566	1906-1503 BC
TX-3663	Burnt wood	G-11:G-8 Floor 9	3540±50	1889-1749 BC	1962-1683 BC
UGa-4583	Burnt wood	H-11:EF-10, Floor 30	3590±75	2009(1.5%)2003 BC 1977(66.7%)1769	2132(4.0%)2084 BC 2057(91.4%)1688
TX-4448	Charcoal	H-11:FG10, Floor 15	3650±60	2115(4.2%)2100 BC 2038(64.0%)1886	2141-1771BC
TX-3166	Burnt wood	C-11: J-6, Floors 3,5,7	3660±80	2133(12.8%)2081BC 2061(55.4%)1883	2204-1748 BC
UCIAMS-185290	Human bone	C-12:D-1; Gallery	3665±15	2024-1947 BC	2116(3.0%)2099 BC 2038(92.4%)1901
TX-4447	Burnt wood	H-11:EF-10, Floor 30	3670±70	2131(13.0%)2086 BC 2051(55.2%)1893	2201(88.3%)1863 BC 1851(7.1%)1772
TX-2463	Burnt wood	Sector D gallery	3740±90	2266(0.9%)2261BC 2206(67.3%)1947	2454(1.3%)2419 BC 2407(1.3%)2377 2351(91.8%)1877 1840(0.6%)1825 1794(0.4%)1783
UCIAMS--185730	Human bone	C-11:F-5; Chamber	3770±15	2196(19.7%)2171 BC 2147(14.6%)2128 2089(33.9%)2046	2201(52.4%)2110 BC 2105(43.0%)2036
MAMS-27354	Human bone	C-10:I1-0; Gallery	3780±15	2199(31.8%)2160 BC 2154(16.8%)2131 2085(19.7%)2055	2269(1.2%)2260 BC 2206(94.2%)2036
TX-4449	Charcoal	E-12: I2, Floor 6	3790±70	2334(1.3%)2325 2301(64.7%)2017 1995(2.2%)1981	2466-1911

UCIAMS--185731	Human bone	D-11:C-3; Chamber	3800±20	2271(15.3%)2259 BC 2207(60.8%)2135 2070(2.1%)2065	2286(11.7%)2247 BC 2235(68.7%)2121 2094(14.9%)2042
TX-3167	Burnt wood	D-11: C-3, Floor 25	3820±60	2296(59.4%)2130 2086(8.8%)2050	2456(3.6%)2418 2408(3.7%)2374 2368(68.2%)2030
UCIAMS-185733	Human bone	F-12:B-2; Chamber	3820±20	2278(18.2%)2251 BC 2229(4.5%)2221 2211(15.0%)2190 2181(30.5%)2142	2295(91.8%)2131 BC 2085(3.6%)2057
TX-4450	Charcoal	F-12: B-2, firepit	3820±100	2389(0.6%)2386 2346(67.6%)2036	2476-1926
TX-3664	Burnt wood	I-11: D-5, related to floor 40	4110±50	2840(8.5%)2814 2677(44.4%)2559 2536(15.3%)2491	2865(14.5%)2804 2762(80.9%)2472

4.5.2 Stable isotope data

Atomic C/N ratios calculated for all samples range between 2.9 and 3.6, suggesting bone and tooth collagen was well preserved (Ambrose and Norr 1993; DeNiro and Hastorf 1985). The $\delta^{13}C$ values of human collagen from La Galgada range from -22.2‰ to -12.9‰ with an average value of -18.2‰, whereas the $\delta^{15}N$ values range from 5.8‰ to 11.3‰ with an average value of 8.1‰ (Table 4.4, Figure 4.4).

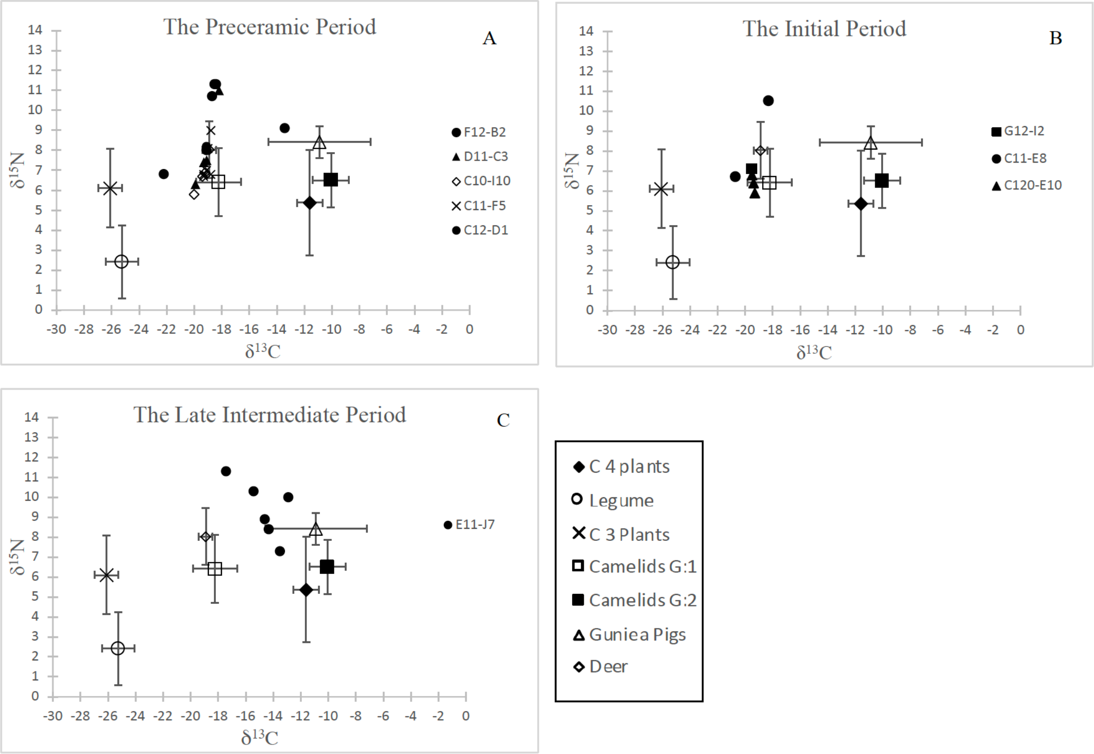

Figure 4.4: Bulk stable isotope data from archaeological human remains at La Galgada, grouped by tomb association (see Table 4.4) as well as potential food resources in the region.

Using a one-way ANOVA test, we found significant differences (F (2,29) = 22.53, p=.0001)) in $\delta^{13}C$ values, when comparing individuals dating to all three time periods (i.e. the Late Preceramic (n=20), Initial (n=6) and Late Intermediate (n=6) Periods). A Tukey-Kramer post-hoc test was used due to unequal sample sizes, to evaluate which groups significantly differed from one another other. The benefit of this post-hoc test is in its ability to determine significance between two groups while taking into consideration all data. This is in contrast to a traditional t-test which requires the systematic comparison of two groups while ignoring the group not under investigation. If the calculated Q value $\geq Q_{crit}$ (based on Q-table) then a significant difference is detected. Alternatively, if our calculated Q value is $< Q_{crit}$ then no significant difference was detected between groups. This test demonstrated that while the $\delta^{13}C$ values of Late Preceramic and Initial Period individuals did not differ significantly at $\alpha=0.05$ $((Q_{crit}) = 3.493$ $Q_{calculated} = 1.07)$, there is a significant difference between the $\delta^{13}C$ values of both the Late Preceramic and Initial Periods when compared to the Late Intermediate Period values (Late Preceramic to LIP: $((Q_{crit}) = 3.493 < Q = 8.93)$; Initial to LIP: $((Q_{crit}) = 3.493 < Q_{calculated} = 8.06)$.

Additionally, there are significant differences in $\delta^{15}N$ values between all compared time periods (F (2,29) = 3.52, p=0.04). A Tukey-Kramer post hoc test determined that there is no significant difference in $\delta^{15}N$ values between the Late Preceramic and Initial Periods $((Q_{crit}) = 3.493 > Q_{calculated} = 1.58)$, but there is a significant difference between $\delta^{15}N$ values from the Late Intermediate Period and the Late Preceramic Period $((Q_{crit}) = 3.493 > Q_{calculated} = 4.02)$ as well as the Initial Periods (p=0.4$((Q_{crit}) = 3.493 < Q_{calculated} = 4.51)$.

Table 4.4: Archaeological contexts and stable isotope values from human samples from La Galgada

No.	Sample	Tomb	Sex	*Age*	Bone/ Tooth	δ^{13}C (‰) collagen	δ^{15}N (‰) collagen	C/N (%)	Atomic C/N
1	LGA 18 MAL 21	Tomb F-12:B-2	?	Adult	M^2	-19.1	8.2	2.9	3.4
2	LGA 26 MAL 31	Tomb D-11:C-3	?	45-50	Metatarsal	-18.2	11	3.0	3.5
3	LGA 40 MAL 45	Tomb D-11:C-3	?	Adult	M_2	-19.3	7.4	2.9	3.4
4	LGA 41 MAL 46	Tomb D-11:C-3	?	Adult	M_3	-19.9	6.3	2.9	3.4
5	LGA 42 MAL 47	Tomb D-11:C-3	?	Adult	M_3	-19.1	7.5	2.9	3.4
6	LGA 3 MAL 05	Tomb C-10:I-10	?	Adult	M_3	-19.4	6.7	3.0	3.5
7	LGA 38 MAL 43	Tomb C-10:I-10	?	Adult	Metacarpal	-19.2	6.9	2.9	3.4
8	LGA 43 MAL 48	Tomb C-10:I-10	?	Adult	Metatarsal	-20.0	5.8	3.0	3.5
9	LGA 4 MAL 06	Tomb C-11:F-5	M	Adult	M_3	-19.3	6.8	3.2	3.7
10	LGA 7 MAL 09	Tomb C-11:F-5	?	Adult	Metatarsal 1	-19.3	6.7	3.0	3.5
11	LGA 8 MAL 10	Tomb C-11:F-5	?	Adult	Metatarsal 1	-19.1	7	2.9	3.4
12	LGA 22 MAL 26	Tomb C-11:F-5	?	Adult	M^3	-19	8.1	3.0	3.5
13	LGA 23 MAL 27	Tomb C-11:F-5	?	Adult	Metacarpal	-18.8	6.8	3.0	3.5
14	LGA 24 MAL 28	Tomb C-11:F-5	?	Adult	M^2	-18.8	9	3.2	3.7
15	LGA 13 MAL 16	Tomb C-12:D-1	F	Adult	M_3	-13.4	9.1	2.9	3.4
16	LGA 14 MAL 17	Tomb C-12:D-1	?	Adult	M_3	-18.4	11.3	2.9	3.4
17	LGA 15 MAL 18	Tomb C-12:D-1	?	Adult	M_3	-18.5	11.3	2.9	3.4
18	LGA 16 MAL 19	Tomb C-12:D-1	?	Adult	M_3	-18.7	10.7	2.9	3.4
19	LGA 17 MAL 20	Tomb C-12:D-1	?	Adult	Metatarsal	-19.1	8	3.1	3.6
20	LGA 20 MAL 23	Tomb C-12:D-1	?	Adult	Cranial Frag.	-22.2	6.8	2.9	3.4
21	LGA 2 MAL 04	Tomb G:12:I-2	?	Adult	Metatarsal 1	-19.5	7.1	3.0	3.5
22	LGA 11 MAL 13	Tomb C-11:E-8	?	Adult	Metatarsal 1	-20.7	6.7	3.3	3.9
23	LGA 44 MAL 49	Tomb C-11:E-8	?	Adult	M_2	-18.3	10.5	2.9	3.4
24	LGA 12 MAL 14	Tomb C-10:E-10	F	Adult	M_2	-19.4	6.4	2.9	3.4
25	LGA 12 MAL 15	Tomb C-10:E-10	F	Adult	Metatarsal	-19.3	5.9	2.9	3.4
26	LGA 21 MAL 24	Tomb C-10:E-10	F	40-70	M^2	-19.5	6.8	2.9	3.4
27	LGA 29 MAL 34	Tomb E-11:J-7	?	Juvenile	M_2	-14.6	8.9	2.9	3.4
28	LGA 30 MAL 35	Tomb E-11:J-7	?	Young Adult	M_2	-17.4	11.3	3.2	3.7

29	LGA 31 MAL 36	Tomb E-11:J-7	?	30-45	M_2	-12.9	10	2.9	3.4
30	LGA 33 MAL 38	Tomb E-11:J-7	?	Adult	Metatarsal	-15.4	10.3	3.0	3.5
31	LGA 34 MAL 39	Tomb E-11:J-7	?	Adult	Metatarsal	-14.3	10.6	3.1	3.6
32	LGA 35 MAL 40	Tomb E-11:J-7	?	Adult	Metatarsal 1	-13.5	10.1	2.9	3.4

To assess the proportions of potential food resources (i.e. C_4, C_3, leguminous plants, camelids and guinea pigs) in each individuals diet at La Galgada we ran a SIAR Mixing Model. Each individuals $\delta^{13}C$ and $\delta^{15}N$ value was input into the model and sorted by the tomb context in which the remains were found. The SIAR mixing model averages these input values for each tomb context and estimates the probability of the percentage (i.e. 25, 75, 95%) of diet for each dietary source. Each graph in Figure 4.5 represents a dietary source. These graphs can be viewed individually to compare a specific dietary source between multiple tomb contexts or as a whole to estimate the proportion of each dietary source per tomb context in relation to an estimated “complete” diet.

4.5.2.a Late Preceramic Period and Initial Period Model Results

The results of these simulations suggest that the majority of individuals from tombs dating to the Late Preceramic and Initial Periods have diets consisting of primarily C_3 plants and low levels of terrestrial meat consumption (Figure 4.5). C_3 plants make up to 40% of modeled diet for individuals during this time period (Figure 4.5A). Leguminous and C_4 plant consumption are more varied throughout these two cultural time periods (Figure 4.5B, 4.5C). The majority of tombs have an average leguminous plant consumption of up to 30% of the modeled diet. When analyzing the 25 and 75% credibility intervals, tomb C-11:F-5 has a lower percentage of leguminous plant consumption of up to only 15% (Figure 4.5C).

The mixing model results for the consumption of C_4 plants (i.e. hypothesized maize consumption) are more varied across both time periods (Figure 4.5B). During the Late Preceramic period, tomb F12-B2 averages 15% consumption, although there is only one individual tested from this tomb. Tombs D-11:C-3, C-10:I-10, C-11:F-5, and C-12:D-1 are consuming essentially no C_4 plants when comparing the 25% credibility intervals.

An analysis of meat consumption during the Late Preceramic and Initial Periods shows an average consumption of 20% and up to 30% for grazing camelids (camelids - group 1; Figure 4.5D) and locally sourced deer. Tomb C-11:F-5 has a 95% confidence interval of up to 60% deer consumption. As C_4 consumption is low during these time periods, the model estimates the consumption of foddered camelids (camelids - group 2; Figure 4.5E) and guinea pigs (Figure 4.5G) as following the same pattern as C_4 plant usage.

4.5.2.b Late Intermediate Period Model Results

Diet during the LIP changes drastically, this result is not surprising however, due to the significant time gap between site usage and the potential different populations present in the valley during this time period. C_3 plant consumption drops significantly to as low as 15% of the modeled diet (Figure 4.5A) while C_4 plant consumption increased to 30% (Figure 4.5B). There are virtually no leguminous plants consumed during this time period (Figure 4.5C) as well as low levels of wild camelids (Figure 4.5D). Foddered camelids make up to 35% of the estimated diet, while all other meat sources (i.e. guinea pigs and deer) remain important dietary sources as well (Figure 4.5F, 4.5G).

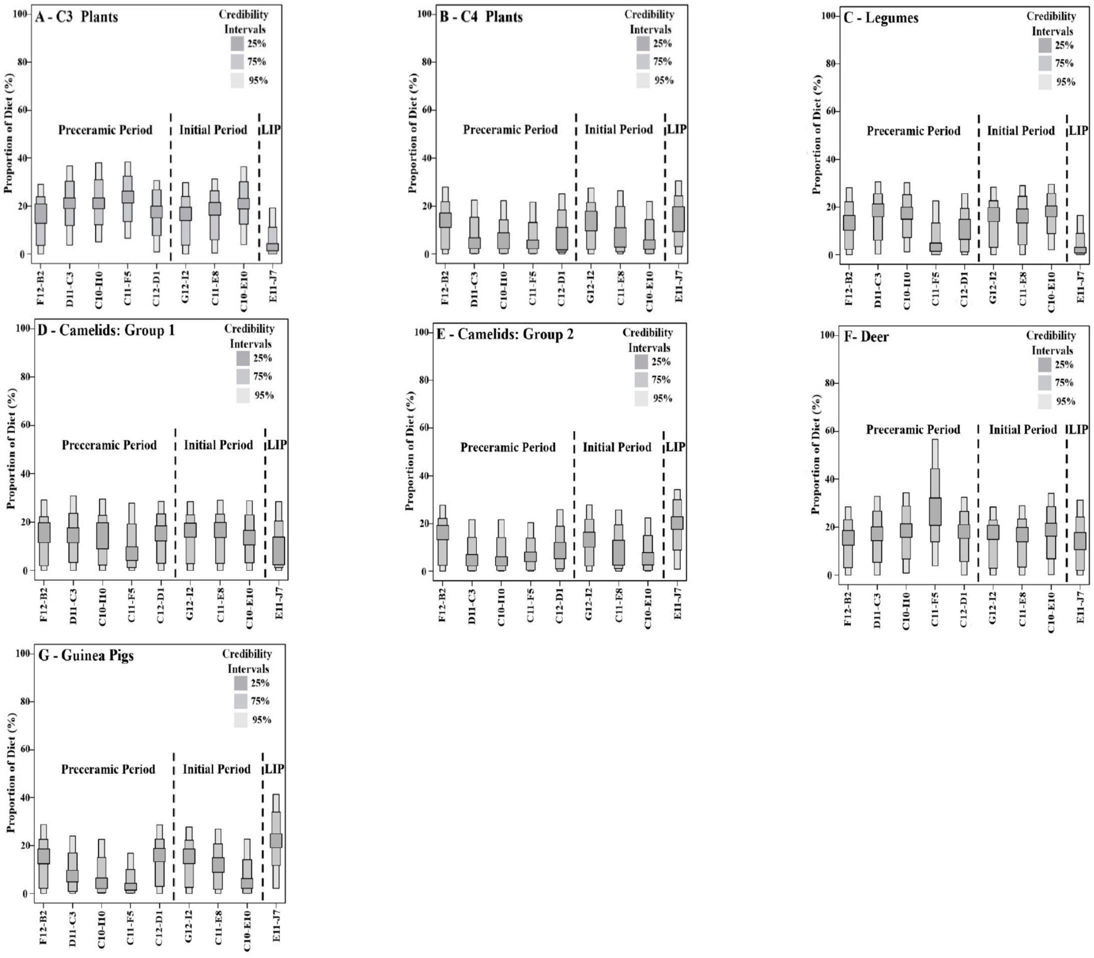

Figure 4.5: Results of the SIAR Mixing Models of human diets at La Galgada shown for the five main potential food resources. 25, 75 and 95% credibility intervals are plotted for each tomb context (see table 4 for detailed description of each tomb context

4.6 Discussion

4.6.1 The use of mixing models to reconstruct diet

In this study, we used a dietary mixing model in order to move beyond the purely descriptive nature of stable isotope studies and to provide more quantitative information on what foods contributed to past diets in the Andes (Bogaard and Outram 2013; Coutts et al. 2011; Finucane 2007; Kellner and Schoeninger 2008; Turner et al. 2010; Turner and Armelagos 2012). The use of mixing models to determine the proportions of dietary sources have many benefits, including providing a statistical method to examine food source contribution, which allows for an empirical assessment of past subsistence (Koch and Phillips 2002; Moore and Semmens 2008**;** Parnell et al. 2010, 2013; Philips 2012**;** Phillips and Koch 2002; Robbins et al. 2002). There are, however, several key limitations that may significantly affect the outcome of a model.

First, model accuracy is limited by the quality and quantity of available food source data. Second, the model lacks the ability to accurately distinguish between source groups that overlap in their isotope values. This can present a challenge when inputting data for groups who isotopic signatures are quite similar. For example, in this study all guinea pigs were grouped together as a potential food source despite their large variation in isotope values and there is slight isotopic overlap between this group, C_4 plants and Camelids: Group 2. Third, the more potential food sources input for a model the lower the resolution becomes. This model has a limit of 30 groups (i.e. tomb contexts - n=9) and between 3-7 observations (i.e. dietary source groups;

n=7). Despite these limitations, mixing models allow us to estimate, quantify and discuss the relative contribution of certain food categories to past human diets, which is of considerable value to the archeological interpretation of past lifeways.

4.6.2 Human diet at La Galgada during the Late Preceramic and Initial Periods

At La Galgada no faunal remains were found. This surprising lack of faunal remains and the relative abundance of botanical remains found and analyzed (Smith 1988) have been used to suggest a primarily plant-based diet focusing on available C_3 and Leguminious plants (Grieder et al.1988), although the excavations primarily focused on the monumental architectural complex. The majority of food remains were found both within the complex and within fire-pits found within burial chambers.

Interestingly, given the potential for missed remnants of food remains, our isotope data suggests that the majority of individuals found dating to the occupation of this site exhibit a dietary pattern consistent with the interpretations made by Grieder and colleagues (1988). Diet consisted of a primarily C_3 plant-based diet with only limited amounts of terrestrial protein (Figure 4.3 and 4.5).

There are, however, several interesting deviations from this overall pattern. First, our isotope data indicates that three adult individuals from tomb C-12:D-1 (LGA 14, 15, 16 – sex unknown) that dates to the Late Preceramic Period, show elevated $\delta^{15}N$ indicating a potentially higher reliance on terrestrial protein when compared with other contemporary burials (Figure 4.4A). Our data suggests that there is little change in the pattern of meat consumption between the Late Preceramic and the Initial Periods; though this is not surprising since in highland Ancash domesticated camelids did not displace hunted animals until around 800 cal B.C.E. (Miller and Burger 1995, Miller 1984; Rosenfeld and Sayre 2016; Sawyer 1985; Uzawa 2010).

Second, one adult female (LGA 13) from burial C:12-D:1 exhibits a higher bulk δ^{13}C value (-13.4‰), falling within the expected range of C_4 plants, possibly indicating high maize consumption (Figure 4.4A). While this individual is unique compared with other contemporary individuals, the potential consumption of maize by this individual, fits with the idea that while present, maize did not become a dietary staple until much later. It is also possible that this individual was not local to La Galgada but migrated to the site, however this interpretation has not yet been substantiated.

4.6.3 Human Diet at La Galgada during the Late Intermediate Period

Gallery tomb E-11:J-7 (n=6), which based on our radiocarbon dates, dates to the Late Intermediate Period, exhibits a considerable change in subsistence. Individuals buried in this tomb show an increased proportion of foddered camelid (camelids - group 2) and guinea pig consumption and a lower proportion of C_3 plants and leguminous plants in the modeled diet (Figure 4.5). C_4 plant consumption seems to have remained low at ~30%, however, this could alternatively be explained by the increase in the proportion of foddered camelids and guinea pigs who also fed on C_4 plants (see further discussion below).

4.6.4 Maize consumption during the Late Preceramic, Initial and Late Intermediate Periods

While maize was present in archaeological assemblages from Peru since approximately 6500 cal BP (Dillehay 2017; Grobman et al. 2012), our data suggest its utilization as an important staple food did not seem to have occurred rapidly at La Galgada. This pattern of the intermittent use of maize, seems may be dependent on ecological zone productivity. In addition, during the Late Preceramic Period, archaeological evidence from the highlands suggests that animal protein was largely derived from deer, wild camelids and small game like vizcachas and guinea pigs (Sawyer 1985; Wing 1972). Archaeological evidence suggests that during the Initial Period reliance on irrigation farming increased, however, the cultigens utilized remain based on ecological zonation (Burger and Van der Merwe 1990) and as such diet did not change drastically.

The results of this study confirm that during the Late Preceramic and Initial Periods, individual diet remained reliant on local productivity with a mixed subsistence economy characterized by a heavy reliance on plants. Except for one individual (LGA13) there are no observed changes of δ^{13}C values coincident with the transition into the Initial Period that would suggest a dietary shift to a largely maize based diet (Figure 4.5B). Thus, it is probable that consumption of maize was not a common practice yet, even if maize itself was known to the region.

Subsistence practices in the Tablachaca Valley between the abandonment of La Galgada and the re-use of the site during the LIP changed significantly. Subsistence practices during the LIP include an increase in intensive agriculture as well as animal husbandry. $\delta^{13}C$ and $\delta^{15}N$ isotope values (Figure 4.4) of all individuals dating to the LIP suggest consumption of a primarily C_4 plant-based diet (i.e. presumably maize). In the Andes, this observation has commonly been used to indicate human primary consumption of maize. However, the use of dietary mixing models may challenge this assumption by taking the analysis of carbon and nitrogen isotope data an important step further by allowing us to distinguish between different proportions of food categories.

When plotted against each other, the bulk $\delta^{13}C$ and $\delta^{15}N$ isotope data clearly shows a C_4 signal in the diet of all LIP individuals (Figure 4.4C). But, does this signal indicate primary consumption of maize or is this signal an indicator of the consumption animals that were feed through the cultivation of mainly maize?

According to our dietary simulations, individuals buried in tomb E-11:J-7, actually do not show a significant increase in the proportion of maize in the diet (~15-30%; Figure 5B), but the proportion of meat did increase (Figure 4.5E, 4.5G). Given that both the foddered camelids and guinea pigs included in this study relied on C_4 plants, it is likely that humans may not be eating maize themselves as eluded to in the isotope data, but rather consuming animals which fed on C_4 plants (Cadwallader et al. 2012). If camelids and guinea pigs are removed from the dietary mixing model the proportion of maize in the diet of individuals buried in E-11:J-7 increases significantly to ~90%, further indicating that the consumption of meat protein from animals that were given maize to supplement their diets likely contributed to the $\delta^{13}C$ and $\delta^{15}N$ isotope values of the humans consuming them. The presence of these particular individuals within the ceremonial center of the then abandoned La Galgada, suggests later usage of the site as a cemetery as no other evidence of later occupation has been discovered.

4.7 Conclusions

This study illustrates that while maize was present in the Tablachaca River Valley at an early date, it was not widely utilized as a dietary staple in either the Late Preceramic or the Initial Periods. This pattern substantiates the idea that subsistence strategies remained dependent on the ecological conditions determined by environmental zones, and did not rapidly shift to maize agriculture once this crop was available. In addition, at least at La Galgada, it was not a dependence on maize agriculture that supported the rapid growth and expansion seen at the site during the Late Preceramic and Initial Periods. Furthermore, this study illustrates the potential benefits in using mixing models to demonstrate potential differences in food resources consumed by past populations through time.

Acknowledgments

We would like to thank the Museo Nacional de Arqueología, Antropología e Historia del Perú (MNAAHP) and the Ministerio de Cultura del Perú for granting us the permission to work with the La Galgada specimens. The permission for sampling and research was obtained under the Resolución Directoral Nacional No. 1346, 545-2011. We also want to thank Susan Kuzminsky and Colin Carney for their continued support and empirical contributions to this research, Bebel Ibarra for the creation of our map, and Rachel Johnson and Alana Garvey for their comments and suggestions. Finally, this manuscript benefited greatly from suggestions from two anonymous reviewers. This research was funded by the National Science Foundation (NSF - 1842447); the German Research Foundation (DFG - FE 1161/1-1); and by start-up grants of the University of California, Santa Cruz.

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Appendix 4.1

All dietary source data used in mixing model simulations. Source data was limited to ecological zones with similar conditions to La Galgada and was compiled from DeNiro and Hastorf (1985), Finucane et al (2006) and Turner et al (2010). Dietary plant data compiled from DeNiro and Hastorf (1985) was limited to modern uncarbonized plants.

Family	Genus & Species	Portion	Common Name	Photo. Path	Original Cat. No.	$\delta^{13}C$	$\delta^{15}N$	Source
Poaceae	*Zea mays*	Seed	Maize	C_4	086	-10.8	7.9	DeNiro and Hastorf, 1985
	Zea mays	Seed	Maize	C_4	086d	-11.6	8.1	DeNiro and Hastorf, 1985
	Zea mays	Seed	Maize	C_4	086g	-14.3	6.6	DeNiro and Hastorf, 1985
	Zea mays	Seed	Maize	C_4	086dg	-12.0	8.5	DeNiro and Hastorf, 1985
	Zea mays	Seed	Maize	C_4	086dgh	-11.8	8.6	DeNiro and Hastorf, 1985
	Zea mays	Seed	Maize	C_4	086dghi	-11.6	7.4	DeNiro and Hastorf, 1985
	Zea mays	Cob	Maize	C_4	126-1	-11.4	3.6	DeNiro and Hastorf, 1985
	Zea mays	Cob	Maize	C_4	126-1b	-11.6	2.9	DeNiro and Hastorf, 1985
	Zea mays	Cob	Maize	C_4	126-1c	-12.2	2.1	DeNiro and Hastorf, 1985
	Zea mays	Cob	Maize	C_4	126-1d	-10.3	3.0	DeNiro and Hastorf, 1985
	Zea mays	Cob	Maize	C_4	126-1bd	-11.4	2.5	DeNiro and Hastorf, 1985
	Zea mays	Cob	Maize	C_4	126-1cd	-11.3	2.3	DeNiro and Hastorf, 1985
	Zea mays	Cob	Maize	C_4	126-1e	-10.9	4,7	DeNiro and Hastorf, 1985
	Zea mays	Cob	Maize	C_4	126-2	-11.2	3.9	DeNiro and Hastorf, 1985
Fabaceae	*Archchis hypogaea*	Seed	Peanut	legume	285-1	-26.7	0.6	DeNiro and Hastorf, 1985
	Archchis hypogaea	Husk	Peanut	legume	285-2	-25.8	1.2	DeNiro and Hastorf, 1985
	Lupinus mutabilu	Seed	Tarwi	legume	061	-23.2	0.4	DeNiro and Hastorf, 1985
	Lupinus mutabilu	Seed	Tarwi	legume	061d	-25.9	2.0	DeNiro and Hastorf, 1985
	Pachyrhizus erosus	Root	Jícama	legume	125	-24.8	2.4	DeNiro and Hastorf, 1985
	Pachyrhizus erosus	Root	Jícama	legume	125b	-25.9	2.5	DeNiro and Hastorf, 1985
	Pachyrhizus erosus	Root	Jícama	legume	125c	-24.8	3.2	DeNiro and Hastorf, 1985
	Pachyrhizus erosus	Root	Jícama	legume	125d	-25.7	2.3	DeNiro and Hastorf, 1985
	Pachyrhizus erosus	Root	Jícama	legume	125bd	-25.8	2.9	DeNiro and Hastorf, 1985
	Pachyrhizus erosus	Root	Jícama	legume	125cd	-24.6	3.0	DeNiro and Hastorf, 1985
	Pachyrhizus erosus	Root	Jícama	legume	125e	-24.8	3.6	DeNiro and Hastorf, 1985

	Phaseolus lunatus	Seed	Lima Bean	legume	076	-24.9	-0.2	DeNiro and Hastorf, 1985
	Phaseolus lunatus	Seed	Lima Bean	legume	076d	-21.7	1.3	DeNiro and Hastorf, 1985
	Phaseoleum lunatus	Seed	Lima Bean	legume	N.A.	–25.0	0.9	Turner et al., 2010
	Phaseoleum lunatus	Seed	Lima Bean	legume	N.A.	–25.0	0.2	Turner et al., 2010
	Phaseoleum lunatus	Seed	Lima Bean	legume	N.A.	–26.0	0.1	Turner et al., 2010
	Phaseoleum lunatus	Seed	Lima Bean	legume	N.A.	–24.1	0.9	Turner et al., 2010
	Phaseoleum lunatus	Seed	Lima Bean	legume	N.A.	–24.3	1.4	Turner et al., 2010
	Phaseoleum lunatus	Seed	Lima Bean	legume	N.A.	–24.2	0.9	Turner et al., 2010
	Phaseoleum lunatus	Seed	Lima Bean	legume	N.A.	–24.7	0.8	Turner et al., 2010
	Phaseoleum lunatus	Seed	Lima Bean	legume	N.A.	–24.8	0.8	Turner et al., 2010
	Phaseoleum lunatus	Seed	Lima Bean	legume	N.A.	–24.8	0.3	Turner et al., 2010
	Phaseoleum lunatus	Seed	Lima Bean	legume	N.A.	–24.8	0.5	Turner et al., 2010
	Phaseolus Vulgaris	Pod	Common Bean	legume	128	-25.9	4.2	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	128b	-26.4	3.5	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	128c	-26.9	6.0	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	128d	-26.4	5.9	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	128bd	-26.5	3.9	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	128cd	-25.2	4.3	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	128e	-26.0	4.5	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Pod	Common Bean	legume	077	-25.4	1.8	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	077d	-25.8	2.8	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	077ghi	-26.9	0.7	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	077dghi	-26.1	2.2	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Pod	Common Bean	legume	232	-24.5	4.0	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Pod	Common Bean	legume	232d	-26.2	4.5	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Pod	Common Bean	legume	232dj	-25.1	3.6	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	226	-25.3	5.7	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	226d	-25.7	**4.4**	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	226j	-26.5	5.9	DeNiro and Hastorf, 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	226dj	-25.9	4.4	DeNiro and Hastorf, 1985
	Pisum sativum	Pod	Common Pea	legume	235	-21.5	0.3	DeNiro and Hastorf, 1985
	Pisum sativum	Pod	Common Pea	legume	235d	-23.6	0.6	DeNiro and Hastorf, 1985
Solanaceae	*Solanum stenotonium*	Tuber		C_3	071	-26.5	5.4	DeNiro and Hastorf, 1985

	Solanum stenotonium	Tuber		C_3	071d	-26.3	6.0	DeNiro and Hastorf, 1985
	Solanum stenotonium	Tuber		C_3	071dg	-26.2	7.8	DeNiro and Hastorf, 1985
	Solanum tuberosum	Tuber	Potato	C_3	229	-26.6	3.4	DeNiro and Hastorf, 1985
	Solanum tuberosum	Tuber	Potato	C_3	229d	-26.8	4.2	DeNiro and Hastorf, 1985
	Solanum tuberosum	Tuber	Potato	C_3	229j	-28.0	5.8	DeNiro and Hastorf, 1985
	Solanum tuberosum	Tuber	Potato	C_3	229dj	-27.1	2.6	DeNiro and Hastorf, 1985
	Capsicum annum	Seed	Sweet and Chili Peppers	C_3	238	-26.4	3.4	DeNiro and Hastorf, 1985
	Capsicum annum	Seed	Sweet and Chili Peppers	C_3	238d	-26.9	2.7	DeNiro and Hastorf, 1985
	Capsicum annum	Seed	Sweet and Chili Peppers	C_3	238j	-26.5	5.6	DeNiro and Hastorf, 1985
	Capsicum annum	Seed	Sweet and Chili Peppers	C_3	238dj	-28.2	2.7	DeNiro and Hastorf, 1985
	Capsicum annum	Seed	Sweet and Chili Peppers	C_3	129	-28.4	3.8	DeNiro and Hastorf, 1985
	Capsicum annum	Seed	Sweet and Chili Peppers	C_3	129b	-29.2	5.5	DeNiro and Hastorf, 1985
	Capsicum annum	Seed	Sweet and Chili Peppers	C_3	129c	-26.7	3.6	DeNiro and Hastorf, 1985
	Capsicum annum	Seed	Sweet and Chili Peppers	C_3	129d	-28.2	0.5	DeNiro and Hastorf, 1985
	Capsicum annum	Seed	Sweet and Chili Peppers	C_3	129bd	-30.0	3.3	DeNiro and Hastorf, 1985
	Capsicum annum	Seed	Sweet and Chili Peppers	C_3	129cd	-27.8	2.2	DeNiro and Hastorf, 1985
	Capsicum annum	Seed	Sweet and Chili Peppers	C_3	129e	-27.6	0.6	DeNiro and Hastorf, 1985
Tropoelacaea	*Tropaeolum tuberosum*	Tuber	Mashua	C_3	072	-25.1	4.2	DeNiro and Hastorf, 1985
	Tropaeolum tuberosum	Tuber	Mashua	C_3	072d	-25.0	5.0	DeNiro and Hastorf, 1985
	Tropaeolum tuberosum	Tuber	Mashua	C_3	072g	-25.6	5.8	DeNiro and Hastorf, 1985
	Tropaeolum tuberosum	Tuber	Mashua	C_3	072dg	-25.0	7.5	DeNiro and Hastorf, 1985
Basellaceae	*Ullucus tuberosus*	Tuber	Ulluco	C_3	067	-23.0	6.4	DeNiro and Hastorf, 1985
	Ullucus tuberosus	Tuber	Ulluco	C_3	067d	-22.9	6.8	DeNiro and Hastorf, 1985
Brassicaceae	*Lepidium meyenii*	Root	Maca	C_3	082	-25.1	2.4	DeNiro and Hastorf, 1985
	Lepidium meyenii	Root	Maca	C_3	082d	-26.7	3.0	DeNiro and Hastorf, 1985
Chenopodiaceae	*Chenopodium quinoa*	Seed	Quinoa	C_3	074	-25.0	4.0	DeNiro and Hastorf, 1985
	Chenopodium quinoa	Seed	Quinoa	C_3	074d	-25.4	6.7	DeNiro and Hastorf, 1985

	Chenopodium quinoa	Seed	Quinoa	C_3	N.A.	–25.2	7.7	Turner et al., 2010
	Chenopodium quinoa	Seed	Quinoa	C_3	N.A.	–26.0	8.7	Turner et al., 2010
	Chenopodium quinoa	Seed	Quinoa	C_3	N.A.	–25.1	8	Turner et al., 2010
	Chenopodium quinoa	Seed	Quinoa	C_3	N.A.	–25.9	8.8	Turner et al., 2010
	Chenopodium quinoa	Seed	Quinoa	C_3	N.A.	–25.2	9	Turner et al., 2010
Cucurbitaceae	*Cucurbita maxima*	Fruit	Squash	C_3	127	-24.8	3.7	DeNiro and Hastorf, 1985
	Cucurbita maxima	Fruit	Squash	C_3	127b	-25.0	2.5	DeNiro and Hastorf, 1985
	Cucurbita maxima	Fruit	Squash	C_3	127c	-24.5	3.3	DeNiro and Hastorf, 1985
	Cucurbita maxima	Fruit	Squash	C_3	127d	-24.6	3.7	DeNiro and Hastorf, 1985
	Cucurbita maxima	Fruit	Squash	C_3	127bd	-25.0	3.3	DeNiro and Hastorf, 1985
	Cucurbita maxima	Fruit	Squash	C_3	127cd	-23.8	4.0	DeNiro and Hastorf, 1985
	Cucurbita maxima	Fruit	Squash	C_3	127e	-24.2	5.0	DeNiro and Hastorf, 1985
	Cucurbita pepo	Seed	Pumpkin	C_3	241	-25.5	5.7	DeNiro and Hastorf, 1985
	Cucurbita pepo	Seed	Pumpkin	C_3	241d	-25.8	5.2	DeNiro and Hastorf, 1985
	Cucurbita pepo	Seed	Pumpkin	C_3	241j	-27.3	6.8	DeNiro and Hastorf, 1985
	Cucurbita pepo	Seed	Pumpkin	C_3	241dj	-26.7	6.7	DeNiro and Hastorf, 1985
	Lagenaria siceraria	Fruit	Calabash	C_3	079	-25.1	5.2	DeNiro and Hastorf, 1985
	Lagenaria siceraria	Fruit	Calabash	C_3	079d	-25.1	5.4	DeNiro and Hastorf, 1985
	Lagenaria siceraria	Fruit	Calabash	C_3	079g	-25.3	2.7	DeNiro and Hastorf, 1985
	Lagenaria siceraria	Fruit	Calabash	C_3	079dg	-25.0	4.9	DeNiro and Hastorf, 1985
Oxalidaceae	*Oxalis tuberosa*	Pod	Oca	C_3	064	-24.8	3.2	DeNiro and Hastorf, 1985
	Oxalis tuberosa	Pod	Oca	C_3	064d	-25.8	4.2	DeNiro and Hastorf, 1985
	Oxalis tuberosa	Pod	Oca	C_3	064g	-26.1	2.7	DeNiro and Hastorf, 1985
	Oxalis tuberosa	Pod	Oca	C_3	064gh	-26.6	2.4	DeNiro and Hastorf, 1985
	Oxalis tuberosa	Pod	Oca	C_3	064ghi	-26.8	2.2	DeNiro and Hastorf, 1985
	Camelid	Bone				-18.9	5.9	Finucane et al., 2006
	Camelid	Bone				-9.7	7.5	Finucane et al., 2006
	Camelid	Bone				-12.1	6.3	Finucane et al., 2006
	Camelid	Bone				-8.5	4.9	Finucane et al., 2006
	Camelid	Bone				-9	6.3	Finucane et al., 2006
	Camelid	Bone				-11.2	9.6	Finucane et al., 2006
	Camelid	Bone				-11.2	6.4	Finucane et al., 2006
	Camelid	Bone				-11.9	4.6	Finucane et al., 2006
	Camelid	Bone				-16.8	5	Finucane et al., 2006
	Camelid	Bone				-9.8	6.6	Finucane et al., 2006
	Vicugna pacas	Bone				-19.2	8.6	Finucane et al., 2006
	Camelid	Bone				-9.2	6.4	Finucane et al., 2006

Camelid	Bone		-9.3	7.6	Finucane et al., 2006
Camelid	Bone		-19.5	8	Finucane et al., 2006
Camelid	Bone		-8.2	5.1	Finucane et al., 2006
Camelid	Bone		-18.8	8.9	Finucane et al., 2006
Camelid	Bone		-18.5	5	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-11.3	9.3	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-7.4	8.9	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-9.9	8.4	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-12.4	8.3	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-18.6	8.2	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-16.1	8.7	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-11.8	9.1	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-7	10.3	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-12.6	7.8	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-7.6	7.4	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-14.6	7.9	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-6.4	7.4	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-8.2	8.1	Finucane et al., 2006
Cavia porcellus	Bone	guinea pig	-8.5	8.1	Finucane et al., 2006

Appendix 4.2

$\delta^{13}C$ and $\delta^{15}N$ isotope values from four deer excavated from the highland archaeological site of Canchas Uckro.

Sample ID	**Provenience**	**Species**	**Material**	**$\delta^{13}C$**	**$\delta^{15}N$**	**Atomic C/N**
CUO-NH-1	Unit 7B layer 1	*Odocoileus virginianus*	Dentine	-19.4	8.6	3.9
CUO-NH-3	Unit 7B layer 2	*Odocoileus virginianus*	Bone	-18.7	8.9	3.9
CUO-NH-4	Unit 8D layer 2	*Odocoileus virginianus*	Dentine	-18.8	8.7	3.8
CUO-NH-5	Unit 8C Layer 2	*Odocoileus virginianus*	Dentine	-18.7	5.9	3.7

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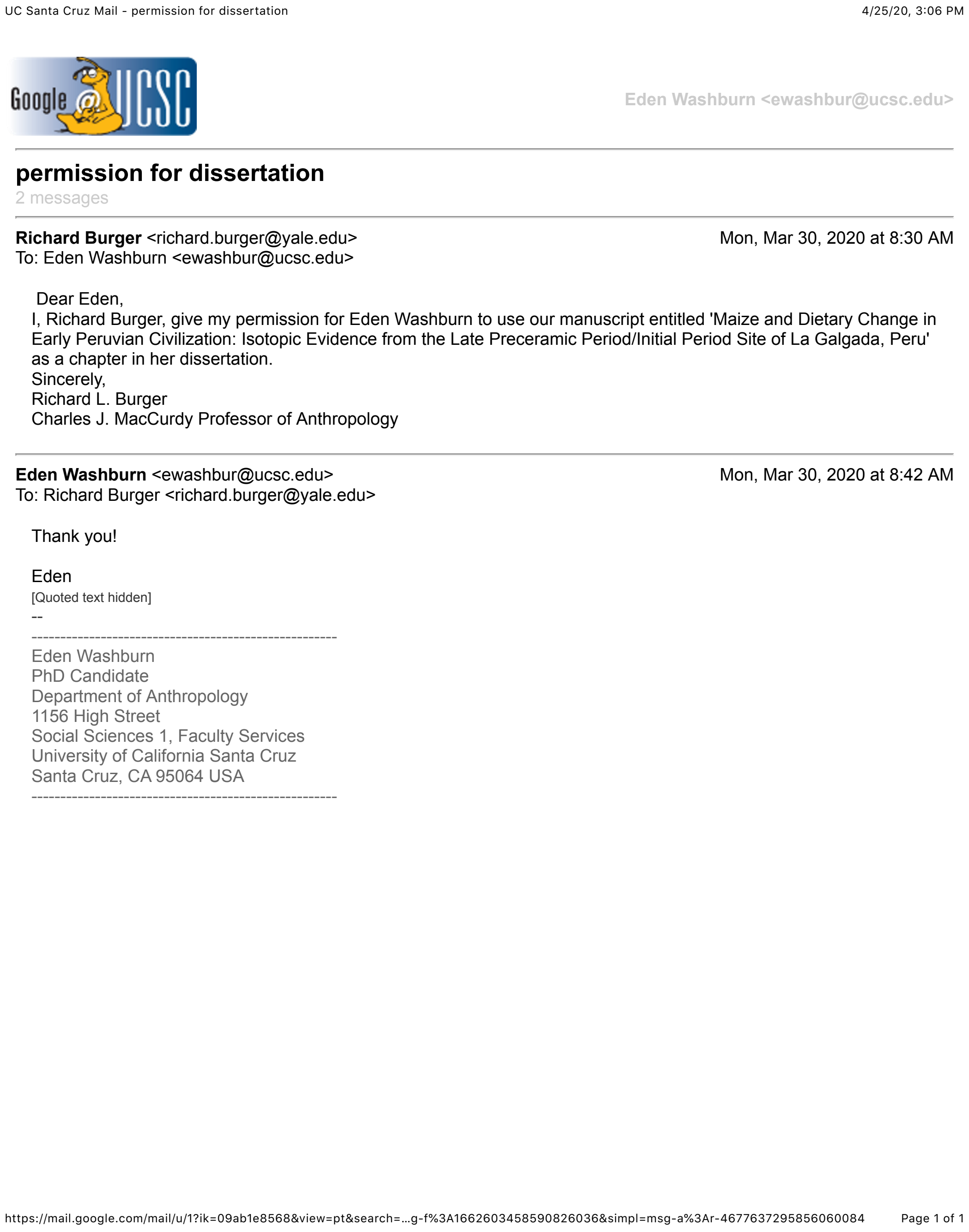

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Thank you!

Eden
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--

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CHAPTER 5

A strontium isoscape for the Callejón de Conchucos of highland Peru and its application to Andean archaeology

Authors: Eden Washburn*[1], Jason Nesbitt[2¶], Bebel Ibarra[2¶], Lars Fehren-Schmitz[1¶], Vicky M. Oelze[1¶]

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Abstract

Strontium isotope ($^{87}Sr/^{86}Sr$) analysis of human skeletal remains is an important method in archaeology to examine past human mobility and landscape use. $^{87}Sr/^{86}Sr$ signatures of a given location are determined by the age of the underlying bedrock, and these geology specific isotope signatures are incorporated into skeletal tissues through food and water. However, the effective use of this method is highly dependent on a detailed understanding of the extent of isotopic variation found within the region's bedrock and sediment. Without extensive mapping of the bioavailable $^{87}Sr/^{86}Sr$ values across a given region the potential interpretations of "local" *vs*. "non-local" individuals in the archaeological record may be fundamentally flawed. This study presents the results of a systematic survey of modern flora and fauna (n=100) from 13 locations to map the bioavailable $^{87}Sr/^{86}Sr$ signatures of the Callejón de Conchucos, Department of Ancash in the Peruvian Andean Highlands that has been left out of previous $^{87}Sr/^{86}Sr$ research in Peru. We illustrate the necessity to include all geological formations accessible to human land use in order to document the full extent of possible $^{87}Sr/^{86}Sr$ values in a given region. This study presents the largest regionally specific bioavailable $^{87}Sr/^{86}Sr$ map (2,640 km^2) to date in the Peruvian Andes as a future baseline for archaeological case studies in this part of the Andes. Here we explore the variation in $^{87}Sr/^{86}Sr$ values from the Callejón de Conchucos region of the north-central Peruvian highlands (0.7078-0.7214) and report a similar range in $^{87}Sr/^{86}Sr$ values as reported globally (0.7038-0.7234).

Key words: mobility**,** Peru, Andes bioarchaeology, bioavailable strontium, mapping

5.1 Introduction

The study of mobility and migration are important topics in contemporary archaeology [1]. While human mobility can be studied using a variety of archaeological indicators, recent years have witnessed an increase in investigations that employ isotopic analyses of human remains to study ancient population movements [2-11]. Given that the strontium isotope ($^{87}Sr/^{86}Sr$) signature of a specific location is determined by the age of the underlying bedrock, (i.e., older bedrock will exhibit higher strontium isotope values) [12], these isotopes remain relatively unchanged as they are passed up the food-chain [13-16], and the fact that strontium isotopes have the unique ability to substitute for calcium in the hydroxyapatite of bone and tooth enamel [17], the use of $^{87}Sr/^{86}Sr$ analysis provides a glimpse into past human and animal movement throughout a landscape. With the uptake of only locally sourced nutrients, the $^{87}Sr/^{86}Sr$ values in an organism will reflect the locally bioavailable (i.e., only the strontium which makes its way into the food chain; see further discussion below) signature of the immediate geological location in which an individual lived. Many archaeological studies employing $^{87}Sr/^{86}Sr$ analysis use enamel from both early and late forming teeth to track human mobility between childhood and adolescence [18-24]. Some studies also utilize bone as a sample material (see Table 1), but extensive research on bone diagenesis has shown that bone $^{87}Sr/^{86}Sr$ can be significantly contaminated and biased toward the $^{87}Sr/^{86}Sr$ values of the burial environment [25-29]. Besides issues related to the selection of sample materials, there is another important caveat to the use of $^{87}Sr/^{86}Sr$ analysis in archaeological science which is related to the lack of $^{87}Sr/^{86}Sr$ reference data. In this study, we argue that human mobility can only be traced based on a solid reference data foundation and detailed understanding of the range of $^{87}Sr/^{86}Sr$ variation within a landscape [2, 13-15].

The use of $^{87}Sr/^{86}Sr$ isotope analysis to identify non-local individuals in the archaeological record relies solely on an accurate characterization of local $^{87}Sr/^{86}Sr$ ranges. In other words, when using this method, it can prove to be insufficient to solely document the $^{87}Sr/^{86}Sr$ variation in an archaeological assemblage of human remains if no environmental $^{87}Sr/^{86}Sr$ baseline data is available to compare the human values to. Throughout the world, methods for determining the $^{87}Sr/^{86}Sr$ ranges in the environment have been applied at the regional and even countrywide scale. Many studies employing $^{87}Sr/^{86}Sr$ analysis refer to work-around solutions to assess the local $^{87}Sr/^{86}Sr$ setting. In the early days of this method, for example, researchers determined the local range of $^{87}Sr/^{86}Sr$ values as a two-standard deviation ($\pm 2\sigma$) range around the average $^{87}Sr/^{86}Sr$ value measured in all archaeological samples from a site, simply characterizing statistical outliers as non-local individuals [30]. However, because statistical means are sensitive to outliers and sample size, calculating the local range in this way is subject to substantial estimation errors [16, 30]. Given the challenges with defining local ranges based on the arbitrary calculations of the $^{87}Sr/^{86}Sr$ values of an ancient (and potentially highly mobile) human population, researchers began to sample local (both archaeological and modern) fauna and flora as proxies for locally biologically available $^{87}Sr/^{86}Sr$ [5, 15, 30-37]. The accuracy and precision of this method depends on the sampling effort and the heterogeneity of geologies in a given area [37].

In recent years, there has been an increased push to create nationalized isoscapes (a spatially explicit prediction of isotopic variation across a landscape [38-41]). These isoscapes take into consideration all published $^{87}Sr/^{86}Sr$ data for a given region and use this dataset to extrapolate the extent of possible $^{87}Sr/^{86}Sr$ values across these large geographic areas [16, 42-49]. While these studies represent an enormous effort to create $^{87}Sr/^{86}Sr$ isocapes for large geographic areas and can potentially provide invaluable insight into the nature of past mobility on a population-wide national scale, we assert that their effectiveness remains dependent on the amount and quality of data used to generate the isoscape.

In the Andes, $^{87}Sr/^{86}Sr$ analysis has been used to address a range of questions about human mobility and adaptations to the Peruvian highlands [21, 31, 32, 35, 36, 50-69]. The vast majority of $^{87}Sr/^{86}Sr$ isotope studies are situated along the Pacific coast, in the southern Andes and west of the Cordillera Blanca, even though dynamic human occupation has a deep history throughout the Central Andes [70-73]. The lack of $^{87}Sr/^{86}Sr$ studies within highland valley systems, particularly east of the Cordillera Blanca, has resulted in the under-estimation of the geologic complexity throughout the region impacting the effectiveness of extrapolating $^{87}Sr/^{86}Sr$ values for these regions. It is because of this geological complexity within the Andes that distinguishing between people of local and non-local origin at a given site or region remain both promising, and at the same time, a challenge. Here, we argue that regionally specific $^{87}Sr/^{86}Sr$ studies that emphasize the necessity to collect environmental samples of biologically available $^{87}Sr/^{86}Sr$ increase the effectiveness of this method.

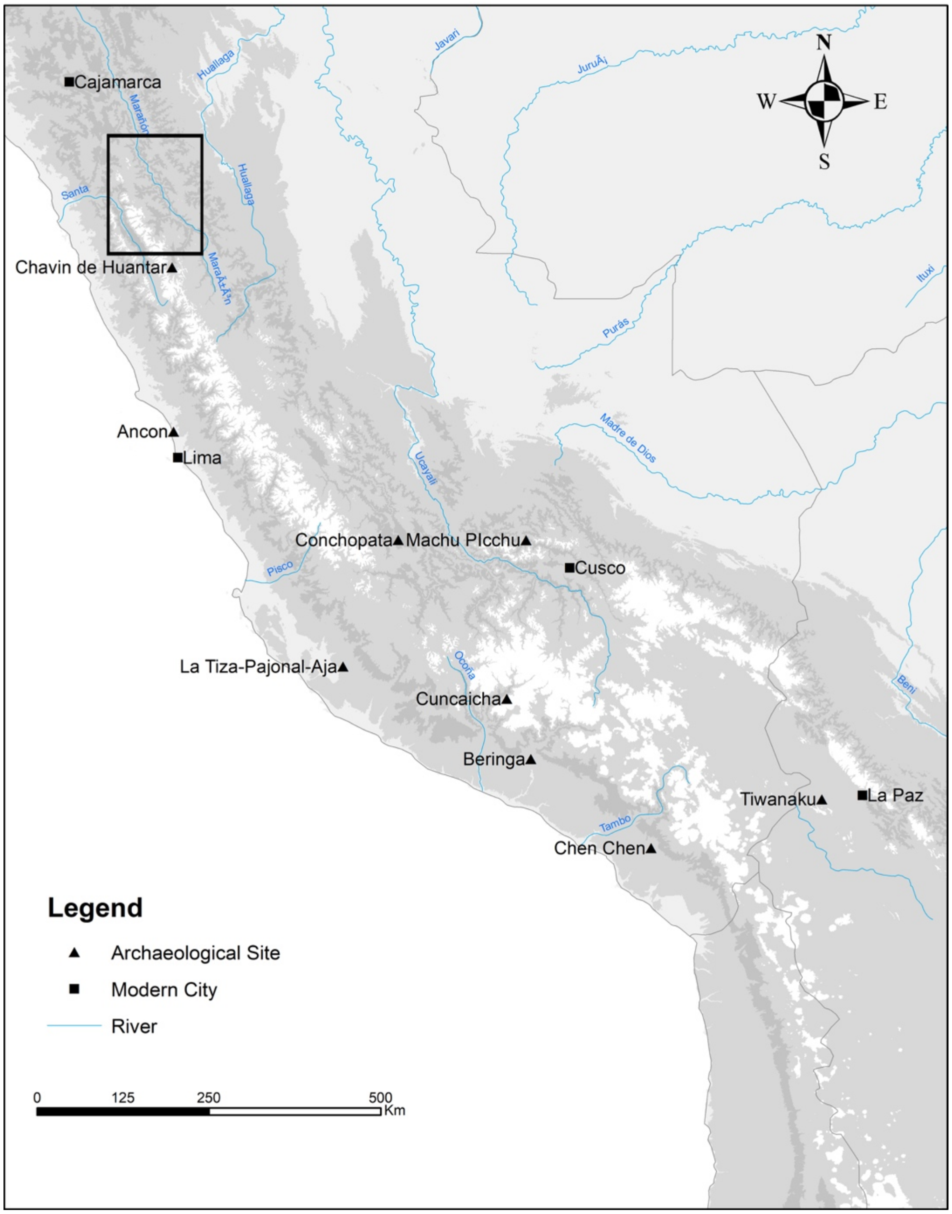

Fig 5.1: Map of Peru with the location of previous $^{87}Sr/^{86}Sr$ isotope studies as well as the Callejón de Conchucos (black square) identified

We present a regional isoscape of the Callejón de Conchucos of the north-central highlands of Peru. Covering an area of 2,640 km², this study presents the most detailed and one of the largest regionally specific bioavailable $^{87}Sr/^{86}Sr$ maps in the Peruvian Andes, particularly east of the Cordillera Blanca. In addition, our study raises new insights to questions related to what constitutes isotope-based determinations of local and non-local populations in Andean archaeology.

5.2 Background

5.2.1 Strontium Geochemistry

In the environment, the trace element strontium (Sr) is found in extremely low concentrations in bedrock, groundwater, soil, plants and animals. Sr is composed of different percentages of the following four stable isotopes: ^{84}Sr (~0.56%), ^{86}Sr (~9.87%), ^{87}Sr (~7.04%) and ^{88}Sr (~82.53%) [74, 75]. Of these four isotopes, ^{87}Sr is radiogenic and formed over time by the radioactive decay of rubidium (^{87}Rb) in the bedrock, which has a half-life of ~4.88 x 10^{10} years. As a result, specific concentrations of ^{87}Sr in the environment are a result of a bedrocks' age and Rb content [12, 13]. Sr enters the biosphere through uptake from the substrate by plants and is passed along the food chain into, for example, the tissues of both animals and humans. The chemical behavior and similar atomic mass of Sr and calcium (Ca) allows Sr to substitute for Ca in the cellular structures of plants, or in the hydroxyapatite of both bone and tooth enamel [17, 76]. In contrast to many commonly utilized light isotope systems, the isotopic composition of Sr does not change or fractionate during biological processes [76]. This is because the mass differences between the four Sr isotopes are relatively small [74-77]. As a result, the $^{87}Sr/^{86}Sr$ values measured in flora and fauna vary solely based on the age of the bedrock on which they sourced their nutrients. Very old bedrock that has high Rb/Sr ratios will have the highest $^{87}Sr/^{86}Sr$ values today [12, 78]. Examples of geological deposits that have relatively high Rb/Sr ratios include clay-rich rocks such as shale, or igneous rocks that have high silica content such as granite, with $^{87}Sr/^{86}Sr$ values up to 0.715 [74]. On the other hand, geologically young rocks and sediments will have low Rb/Sr ratios and typically have $^{87}Sr/^{86}Sr$ less than 0.706 (e.g., [79].

When utilizing $^{87}Sr/^{86}Sr$ analysis in a past or present living system there are several factors that need to be taken into account. First and foremost, the considerable differences between geological substrate $^{87}Sr/^{86}Sr$ and biologically available $^{87}Sr/^{86}Sr$ must be considered [15, 26, 80]. Not all Sr in bedrock is uniformly weathered into the soil and water where it becomes accessible for plants and then animals [14, 15, 75]. Various minerals found within a single bedrock unit can have considerable variability in their $^{87}Sr/^{86}Sr$ values. For example, granite can have two feldspars with radically differing $^{87}Sr/^{86}Sr$ values (plagioclase and potassic feldspars) depending on which section is measured [15]. As such, biologically available $^{87}Sr/^{86}Sr$, which is soluble and is taken up by biotic agents, can substantially differ in its values between the lithosphere and the biosphere [15, 17, 76, 81]. As a result, direct bedrock $^{87}Sr/^{86}Sr$ measurements typically conducted for geological dating studies [65, 82-87] are not necessarily accurate for applications in archaeological science. Besides Sr deriving from the weathering of local bedrock, atmospheric and surface sources such as rainfall, rivers, sea-spray, and wind-dust also contribute to the bioavailable Sr in the food chain [5, 13, 88, 89]. Modern anthropogenic Sr contaminations can be introduced through industrial fertilizers and even via dust from large scale construction sites [13, 15, 44, 49]. As organisms consume local food and water, these various sources of Sr are mixed and incorporated into their body tissue. To infer the biologically available $^{87}Sr/^{86}Sr$ values in an area, newer studies commonly use samples of uncontaminated environmental sources of local origin such as plants and small animals [13, 49, 90, 91], water [16, 88, 92, 93] and soil [13, 49] samples.

Secondarily, $^{87}Sr/^{86}Sr$ values even from within a single geological formation that is stretched over vast distances can vary significantly depending on weathering exposure, hydrology and biotic factors [15]. Therefore, we recommend documenting the bioavailable $^{87}Sr/^{86}Sr$ values in geological units in proximity of the archaeological site or region under investigation, instead of relying solely on published $^{87}Sr/^{86}Sr$ data from a matching yet geographically distant geological formation. Additionally, multiple samples of different kind per geological unit are useful to determine the variability within the bioavailable $^{87}Sr/^{86}Sr$ values within a geological formation.

5.2.2 $^{87}Sr/^{86}Sr$ Analysis in Archaeology

It is important to note that as biological tissues form at different stages of an individual's life, they will have $^{87}Sr/^{86}Sr$ values that reflect the isotope values of the food and water consumed during the tissue's formation. Enamel of the permanent first molar begins to form in utero, with the complete mineralization occurring within the first three years of life [79, 80]. Enamel formation of the third molar mineralizes approximately 7-16 years after birth [80]. Bone, on the other hand, is constantly remodeled throughout life at variable rates depending on the skeletal element, metabolism and pathology [81]. Tooth enamel is denser and much less susceptible to diagenesis than archaeological bone [15, 55, 82-84] and for this reason, generally produces better quality data. Archaeological bone, which is subject to substantial post-mortem change, should not be used in strontium isotope studies.

While traditional archaeological approaches primarily rely on artifactual and architectural evidence as a proxy for population movement, the use of $^{87}Sr/^{86}Sr$ data obtained from human and faunal skeletal material allows researchers to examine past human mobility at an individual instead of population scale. The vast majority of studies employing $^{87}Sr/^{86}Sr$ analysis focus on the analysis of human skeletal remains from archaeological sites with the intention of identifying immigrants and to track residential mobility in the past (e.g., [3, 7-9, 94, 95]). $^{87}Sr/^{86}Sr$ studies have also been applied to address broader socio-cultural questions relating to imperial strategies [34, 35, 50, 55, 63, 69, 96-98], colonization [35, 98-101], post-marital residential patterns [23, 30, 102, 103], identity [22, 69, 104-106] and warfare [32, 67, 105-109].

However, some of these archaeological studies utilizing $^{87}Sr/^{86}Sr$ analysis may be limited in the precision and accuracy of data interpretations because of the following points:

1) Reliance only on reference materials from the immediate location of interest, often even from within the archaeological complex itself, i.e. using soil from the burials;
2) Referring to $^{87}Sr/^{86}Sr$ values from archeological human skeletal remains to discriminate local from non-local individuals (mean $^{87}Sr/^{86}Sr$ value $\pm 2\sigma$ [18]), disregarding the notion that humans indeed can have very mobile life histories;
3) Referring to modern domestic faunal material which can easily be contaminated with exogenic Sr and may not reflect past local $^{87}Sr/^{86}Sr$ values;
4) Referring exclusively to published geological $^{87}Sr/^{86}Sr$ from geological formations hundreds of km away from the research area;
5) Extrapolating data that may be useful at a gross scale, but comes at poor resolution at a local scale.

In order to mediate these various limitations and to accurately interpret the $^{87}Sr/^{86}Sr$ variation observed in an archaeological context, we recommend documenting the bioavailable $^{87}Sr/^{86}Sr$ variation in the entire area of interest and to build a $^{87}Sr/^{86}Sr$ isoscape of the surrounding region. An isoscape can be created by conducting a systematic environmental $^{87}Sr/^{86}Sr$ survey that targets all larger geological formations in the region of interest [44, 110-112]. Sample locations should avoid areas exposed to obvious anthropogenic contaminations in the environment such as through agriculture (manure, industrial fertilizers, herbicides and pesticides) and/or industry (traffic exhausts, water contamination) [13, 25, 88, 113]. Particularly easy to obtain are samples from sedentary organisms or those with discrete home ranges which are predominantly dependent on the local substrate, such as wild plants or small bodied animals such as snails and rodents [110, 114]. If modern environmental samples are collected from the environment directly, their location and the quality of these samples can be documented. In archaeological fauna, however, it is often not clear if animals were kept locally, remotely, or if they were subject to exchange [5, 19-21]. Depending on the source, even modern domestic fauna may not reflect local $^{87}Sr/^{86}Sr$ values if they were fed imported non-local foods, and/or if fodder was exposed to exogenic Sr though industrial fertilizers. For example, in many Andean $^{87}Sr/^{86}Sr$ studies, cuy (or guinea pig; *Cavia porcellus*) have been used as proxies for bioavailable $^{87}Sr/^{86}Sr$ [14, 15, 22, 55, 83, 84, 108]. These animals are often purchased from local markets and their geographic origin and/or the origin of their fodder remains unknown, making it difficult to associate the obtained $^{87}Sr/^{86}Sr$ data to a specific geological formation with the necessary certainty.

Environmental mapping of bioavailable $^{87}Sr/^{86}Sr$ in a study region allows researchers to establish a highly reliable and accurate baseline $^{87}Sr/^{86}Sr$ map that can be used in future archaeological research. These types of regionally specific $^{87}Sr/^{86}Sr$ studies are necessary to document the extent of geological variability and to fully define local $^{87}Sr/^{86}Sr$ ranges. A highly laudable attempt to provide a nationwide $^{87}Sr/^{86}Sr$ map for future archaeological research in the Andes and beyond was recently conducted by Scaffidi and Knudson [in press, 16]. In this study the authors pulled together published ^{87}Sr/^{86}Sr data from Peru and applied geostatistical modeling to generate an isoscape map for the country. This isoscape has the potential to be particularly valuable in regions lacking ^{87}Sr/^{86}Sr reference data. In this study, we will present new environmental ^{87}Sr/^{86}Sr data that allows us to test the accuracy and precision of the extrapolated data presented by Scaffidi and Knudson [16].

5.2.3 Geology of the Peruvian Andes

As with most mountainous regions, the Andes mountain range is comprised by folded geological layers of various ages [115-117] that generally run in parallel from north to south. These geological formations can be relatively narrow and stacked close together; past inhabitants of the Andes utilized landscapes associated with multiple geological formations. The Andes Mountains are commonly divided into the Cordillera Occidental to the west and the Cordillera Oriental to the east. The Cordillera Occidental is largely composed of late Cenozoic volcanic rocks such as andesites and Mesozoic formations. The age of the Cenozoic volcanic rock increases from the northern Andes to the Southern Andes and as a result the ^{87}Sr/^{86}Sr values are generally higher in the southern part of the Andes [79, 118]. ^{87}Sr/^{86}Sr values reported from late Cenozoic volcanic rocks in Ecuador exhibit ^{87}Sr/^{86}Sr values of 0.70431±0.00016 (1σ, n=23) [118], while exposed bedrock samples from similar geologic formations in northern Chile exhibit mean ^{87}Sr/^{86}Sr values of 0.70646±0.00020 (1σ, n=8) [79]. The Cordillera Oriental in the east is mainly comprised of Paleozoic geology. These formations generally have higher ^{87}Sr/^{86}Sr values than the western Cordillera; however, their $^{87}Sr/^{86}Sr$ values have not yet been measured in bedrock [14, 119].

Geographical and isotopic descriptions of the Andes in these broad terms do not adequately capture all of the geological complexity of this region, as depicted in Fig 5.2. It is because of this geological diversity that archaeologists are employing molecular tools such as $^{87}Sr/^{86}Sr$ analysis (Fig 5.1; Table 5.1) in order to address questions surrounding human life histories and population interactions within the challenging landscape of the Andean mountain range.

A common question in Andean archaeology relates to how mobile individuals were within high altitude environments; where people came from with the formation and use of the large ceremonial/provincial sites found throughout this landscape [e.g., 31, 32, 35, 50, 52, 67]. Table 1 shows details on the sample sizes and materials used in $^{87}Sr/^{86}Sr$ studies from modern day Peru published before 2019 [21, 31, 32, 35, 36, 50-69]; Fig 5.1]. Many $^{87}Sr/^{86}Sr$ studies conducted in the Peruvian Andes rely either on a limited $^{87}Sr/^{86}Sr$ reference sample (created with either archaeological or modern sample materials) or previously published $^{87}Sr/^{86}Sr$ reference data deriving from distant regions or geological mapping studies. As discussed above, these types of $^{87}Sr/^{86}Sr$ studies have limitations as the extent of geological variation and the diversity of $^{87}Sr/^{86}Sr$ values may be under-represented.

Table 5.1: Example ^{87}Sr/^{86}Sr case studies from Peru utilizing ^{87}Sr/^{86}Sr values to determine residential mobility; published before 2019. Early Intermediate Period (EIP): 200 B.C.E.–700 C.E.; Middle Horizon (MH): 700 -1000 C.E.; Late Intermediate Period (LIP):1000-1400 C.E.; Late Horizon (LH): 1476-1534 C.E.

Site	Location	Chronology	Sample Material	No. Ind	Reference material	N	Sampling location	Ref
Cuncaicha rock shelter	Pucuncho Basin	Early Holocene	Enamel	4	Arch fauna	9	Within site	Chala-Aldana et al. 2018
Atacama Desert	Atacama Desert	9000-3000BP	Enamel	35	Arch fauna – Modern fauna (marine and terrestrial)	21	Surrounding region	Standen et al. 2018
Chavín de Huántar	Ancash District	EIP (Recuay 1-700 C.E.)	Enamel	5	Arch fauna modern fauna, soil, plants	10	Within site	Slovak et al. 2018
Conchopata	Ayacucho Basin	EIP – MH	Enamel Bone	38	N/A	N/A	Published data	Tung and Knudson 2011
La Tiza and Pajonal Alto	Nasca Drainage Southern Coast	EIP – LIP	Enamel Bone	10	Arch fauna Modern fauna	16	Within site and surrounding region	Conlee et al. 2009
Aja, Cahuachi, Cantayo, Majoro, Chico, and Paredones	Nasca Drainage	EIP – MH	Enamel	29	N/A	N/A	Published data	Knudson et al. 2009
	Rio Muerto	MH	Enamel Bone	33	N/A	N/A	Published data	Knudson et al. 2014
Tiza	Nasca	MH	Dental Enamel	15	N/A	N/A	Published data	Buzon et al. 2012
Beringa	Majes Valley	MH	Enamel/ Bone	52	Arch and Modern Fauna	11	local farms and within site	Knudson and Tung 2011
Ancón	Central Coast	MH	Enamel/ Bone Pairs	35	N/A	N/A	Published data (Slovak 2007 PhD dissertation)	Slovak et al. 2009
Conchopata	Ayacucho Basin	MH	Enamel/ Bone	11	Arch and Modern Fauna	12	Local markets and within site	Tung and Knudson 2008
Tiwanaku, Chen Chen, Coyo Oriental, Coyo-3, Solcor-3, Tilata, Kirari and Iwawe	Moquegua Valley	MH	Enamel/ Bone	27	Arch and Modern Fauna	13	Surrounding region	Knudson 2008

Conchopata	Ayacucho Basin	MH	Enamel/ Bone	11	Modern	6	Market	Knudson and Tung 2007
Tiwanaku, Chen Chen, Coyo Oriental	Moquegua Valley	MH	Enamel/ Bone	27	Arch and Modern Fauna	13	Purchased from owner and within site	Knudson and Price 2007
Chen Chen and Tiwanaku	Moquegua Valley and Bolivia	MH	Enamel/ Bone	18	Modern	6	Market	Knudson et al. 2004
Pampa de los Gentiles	Chincha Valley	LIP	Enamel	7	N/A	N/A	N/A	Knudson et al. 2016
Ranracancha, Cachi and Pucullu	Andahuaylas	The LIP	Enamel	34	N/A	N/A	N/A	Kurin et al. 2014
Santa Rita B	Chao	LIP	Bone	4	Modern Fauna	6	Within site	Bethard et al. 2008
Chiribaya Polity	Osmore Drainage	LIP	Enamel/ Bone	22	Arch and Modern Fauna	21	Surrounding region	Knudson & Buikstra 2007
Machu Picchu	Cuzco	Inca	Bone	51	N/A	N/A	Published data	Turner & Armelagos 2012
Machu Picchu	Cuzco	Inca	Bone	74	Arch fauna	4	Within site	Turner et al. 2009
Chokepukio	Cuzco	LH	Enamel	59	Arch and Modern Fauna	10	Local markets and within site	Andrushko et al. 2009
Arequipa, Atico, Camaná, Chala, Cusco, Ica, Ilo, Lima, Mejía, Moquegua, Nazca, Ocoña, Palpa, Pisco, Puno, Tacna, and Yauca	Central and Southern Peru	---	---	---	Soil	114	Central and Southern Peru	Knudson et al. 2014

5.3 Material and Study Region

The study area consists of a broad swath of the eastern highlands of north-central Peru known as the Callejón de Conchucos. Conchucos is an intermontane valley situated on the southeastern side of the Cordillera Blanca and is characterized by several river systems that drain into the Marañon River, one of the major tributaries of the Amazon. Our study focused on sample collection over an area of 2,640 km^2 that includes the Huaritambo, Mosna/Puccha, and Marañon rivers. This region is archaeologically rich [e.g., 70], and recent research in the region by Ibarra and Nesbitt have documented archaeological sites dating from ca. 1100 B.C.E. until the 16th century [e.g., 72, 120-123]. Data from this study will be used to interpret individual mobility from archaeological sites within the region in future publications.

As illustrated in Fig 5.2, the Callejón de Conchucos is geologically diverse. The predominant formations comprise folded Mesozoic sedimentary rock formations including sandstones, dark shales, and carbonates (limestone, marls, and dolomites), as well as metamorphic rocks like quartzite and slate [124-126]. The entire region is shaped by these folded and uplifted layers of bedrock which causes the repetition of specific geologic units over a broad region of the Callejón de Conchucos. This is important to consider when defining the categories local and non-local populations in the archaeological record based on ^{87}Sr/^{86}Sr values, as similar geological units can be found throughout the landscape. Towards the north and east the study area is bordered by the geological Marañon Group. Dating to the Proterozoic, Marañon Group rocks are much older than the other geologies, and consist of meta-sedimentary schists, gneiss, and red sandstone [127].

To assess the bioavailable $^{87}Sr/^{86}Sr$ values of the Callejón de Conchucos, we collected the empty shells of modern terrestrial mollusks (Bulimulidae), as well as plant vegetation (*Stipa ichu*) (Table 5.2; Fig 5.2). Empty snail shells are abundant on the landscape and make it unnecessary to obtain live animals. Snails are additionally limited in the extent of their movement throughout their lifetime and can therefore be considered representative of local variability in bioavailable $^{87}Sr/^{86}Sr$ [15, 80, 94, 112]. Sr is deposited in the snail shell, where it substitutes for its main component Ca [128]. Plant $^{87}Sr/^{86}Sr$ values reflect the $^{87}Sr/^{86}Sr$ values in the immediate local soil, as well as $^{87}Sr/^{86}Sr$ admixture introduced by rainwater and atmospheric dust [80].

During field sampling, major geological formations in the region were identified using a geological map (INGEMMET Insituto Geológico, Minero y Metalûrgico 1999 (scale 1:1,100,000). We obtained 100 modern environmental reference samples from 13 sampling sites in six geological units covering a 2,640 km^2 region of the Callejón de Conchucos. In each geological unit, we selected relatively pristine sampling locations where anthropogenic contamination through fertilizers or other pollutants were unlikely as there were no signs of use through agriculture, and there was considerable distance to roads and/or towns. At each location we collected snail shells from the surface alongside several samples of *Stipa ichu* (3-10 plants/unit), a wild perennial grass abundant in the Peruvian highlands. Each sample location was recorded via a hand-held GPS.

5.4 Methods

Sample preparation was conducted in the Primate Ecology and Molecular Anthropology laboratory (PEMA) at the University of California at Santa Cruz (UCSC). Snail shells were repeatedly rinsed with ddH_2O in an ultrasonic bath to remove any attached sediment. Snail shells were then broken into smaller fragments, placed in individual beakers with ultrapure acetone, rinsed in an ultrasonic bath for another 15 mins to remove any potential contaminants on the shell surface and were then set to dry. Plant samples (2g of well dried plant material) and snail shells (~300mg) were then ashed at 800°C for 12 hours in a muffle furnace. The remaining ash (n= 100 samples) was transferred to the UCSC W.M. Keck Isotope Laboratory clean room, where for each sample 20mg of ash from each sample was weighed into clean Teflon beakers and digested for 2 hours in 2ml of 65% HNO_3 on a hot plate set to 120°C. Due the cell structure of plant material complete digestion of plant ash was difficult, thus all plant ash samples were subjected to a microwave digestion in an Anton Paar Multiwave GO Microwave Digestion System. Ashed plant material was combined with 8ml of 65% HNO_3 and 1ml of 6M HCL in a pressure vessel for approximately 30 mins. The dissolved samples of snail shell and microwave digested plants were then placed in open Teflon beakers on a hot plate at 120°C for at least 8 hours to evaporate. Following this, samples were resolved in 1ml of 3M HNO_3. Each sample was carefully transferred into pre-conditioned chromatography columns containing clean Sr-spec^{TM} resin. Samples were reloaded through the resin three times to maximize the amount of Sr attaching to the resin. After 3 washes with 3M HNO_3, the strontium was eluted from the resin with ultrapure ddH_2O into clean Teflon beakers and dried down on a hotplate. The remaining sample, again re-dissolved in 5% HNO_3 was dip checked on the Thermo Finnigan Neptune^{TM} MC-ICP-MS instrument to check the concentration of Sr in each sample. Any sample that had a v^{88}SR value above 40ppm was diluted down to ~40ppm (v^{88}SR). Samples were then measured parallel to the SRM 987 standard, procedural blanks (one/every batch of 9 samples), as well as one clean acid blank after every 5 samples, in a Thermo Finnigan Neptune^{TM} MC-ICP-MS.

5.5 Results

We measured ^{87}Sr/^{86}Sr in 100 environmental samples (50 snail shells and 50 plant samples). Repeated ^{87}Sr/^{86}Sr measurement of the SRM 987 standard resulted in an average value of 0.7093 ±0.00013. The procedural blanks, one for each batch of nine samples, showed negligible amounts of strontium indicating no sample cross contamination. ^{87}Sr/^{86}Sr measured in 50 plant samples range from 0.7071 to 0.7215. ^{87}Sr/^{86}Sr measured in 50 snail shell samples range from 0.7078 to 0.7214 (Table 5.2). Mean ^{87}Sr/^{86}Sr values for each sampling location, as well as more detailed information on each geological unit, are presented in Table 5.2

Table 5.2: Results of ^{87}Sr/^{86}Sr environmental sampling from six geological formations within the Conchucos Region of Peru; sorted by sampling locations

Lab Code	Sample	Geologic Age	Geologic Formation	Latitude	Longitude	^{87}Sr/^{86}Sr	StdErr (%)
HAGS 1	Bulimulidae	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°22’23.8"	W077°07’49.5"	0.7113	0.002
HAGS 2	Bulimulidae	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°22’11.91"	W077°07’49.39"	0.7111	0.002
HAGS 3	Bulimulidae	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°22’14.09"	W077°07’49.47"	0.7104	0.002
HAGS 4	Bulimulidae	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°22’15.74"	W077°07’49.56	0.7114	0.002
HAGS 5	Bulimulidae	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°22’17.40"	W077°07’49.71"	0.7114	0.002
HAGS 6	*Stipa ichu*	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°22’27.7"	W077°07’50.3"	0.7108	0.002
HAGS 7	*Stipa ichu*	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°22.24.9"	W077°07’49.2"	0.7107	0.002
HAGS 8	*Stipa ichu*	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°22’18.33"	W077°07’49.76"	0.7109	0.001
HAGS 9	*Stipa ichu*	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°22’19.66"	W077°07’49.11"	0.7113	0.002
HAGS 10	*Stipa ichu*	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°22’21.26"	W077°07’49.93"	0.7109	0.002
Mean						**0.7110**	**0.002**
HAGS 11	Bulimulidae	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°13’56.7"	W076°58’18.7"	0.7113	0.002
HAGS 12	Bulimulidae	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°13’57.3"	W076°58’18.8"	0.7108	0.002
HAGS 13	Bulimulidae	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°13’48.0"	W076°58’14.2"	0.7139	0.003
HAGS 14	Bulimulidae	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°13’55.5"	W076°58’19.3"	0.7102	0.003
HAGS 15	Bulimulidae	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°13’57.3"	W076°58’17.2"	0.7123	0.003
HAGS 16	*Stipa ichu*	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°13’47.2"	W076°58’13.8"	0.7141	0.002
HAGS 17	*Stipa ichu*	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°13’55.70"	W076°58’17.73"	0.7107	0.001

HAGS 18	*Stipa ichu*	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°13’50.43"	W076°58’14.17"	0.7138	0.002
HAGS 19	*Stipa ichu*	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°13’47.2"	W076°58’13.8"	0.7113	0.002
HAGS 20	*Stipa ichu*	Cenozoic-Mesozoic	Casapalca, Chota, Huaylas	S 09°14’25.2"	W076°54’16.3"	0.7109	0.002
Mean						**0.7119**	**0.002**
HAGS 21	Bulimulidae	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°23’34.7"	W077°08’09.9"	0.7083	0.002
HAGS 22	Bulimulidae	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°23’30.3"	W077°08’06.6"	0.7081	0.001
HAGS 23	Bulimulidae	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°23’35.03"	W077°08’08.62"	0.7078	0.002
HAGS 24	Bulimulidae	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°23’35.77"	W077°08’10.13"	0.7089	0.002
HAGS 25	Bulimulidae	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°23’34.77"	W077°08’11.45"	0.7084	0.001
HAGS 26	*Stipa ichu*	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°23’30.3"	W077°08’06.6"	0.7078	0.002
HAGS 27	*Stipa ichu*	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°23’32.97"	W077°08’11.14"	0.7081	0.002
HAGS 28	*Stipa ichu*	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°23’31.99"	W077°08’06.09"	0.7087	0.002
Mean						**0.7083**	**0.002**
HAGS 29	Bulimulidae	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°15'7.98"	W077°03'22.52"	0.7083	0.002
HAGS 30	Bulimulidae	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°15'3.73"	W077°02'54.14"	0.7092	0.002
HAGS 31	Bulimulidae	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°15'27.39"	W077°03' 37.08"	0.7079	0.002
HAGS 32	Bulimulidae	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°15'39.97"	W077°03'53.99"	0.7087	0.002
HAGS 33	Bulimulidae	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°16'16.30"	W077°03'14.55"	0.7094	0.001
HAGS 34	*Stipa ichu*	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°16'5.40"	W077°02'52.40"	0.7093	0.002
HAGS 35	*Stipa ichu*	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°14' 33.43	W077°03'22.03"	0.7084	0.003

HAGS 36	*Stipa ichu*	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°14'38.64"	W077°04'30.78"	0.7087	0.002
Mean						**0.7087**	**0.002**
HAGS 37	Bulimulidae	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°6'12.97"	W076°56'54.33"	0.7082	0.002
HAGS 38	*Stipa ichu*	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°6'24.25"	W076°56'31.54"	0.7081	0.002
HAGS 39	*Stipa ichu*	Mesozoic	Jumasha, Celendin, Cajamarca	S 09°6'14.00"	W076°56'35.72"	0.7087	0.002
Mean						**0.7083**	**0.002**
HAGS 40	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°24’24.3"	W077°06’09.7"	0.7092	0.002
HAGS 41	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°24’23.06"	W077°06’09.62"	0.7091	0.002
HAGS 42	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°24’23.89"	W077°06’09.40"	0.7087	0.002
HAGS 43	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°24’22.00"	W077°06’09.94"	0.7092	0.002
HAGS 44	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°24’24.3"	W077°06’09.72"	0.7108	0.002
HAGS 45	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°24’22.12"	W077°06’10.46"	0.7092	0.003
HAGS 46	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°24’23.51"	W077°06’10.07"	0.7089	0.003
HAGS 47	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°24’24.88"	W077°06’09.53"	0.7084	0.002
HAGS 48	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°24’24.88"	W077°06’09.10"	0.7082	0.003
HAGS 49	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°24’24.34"	W077°06’09.25"	0.7089	0.002
Mean						**0.7091**	**0.002**
HAGS 50	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°23’21.9"	W077°10’31.9"	0.7158	0.002
HAGS 51	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°23’23.5"	W077°10’34.0"	0.7179	0.002
HAGS 52	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°23’22.8"	W077°10’34.6"	0.7172	0.001
HAGS 53	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°23’21.23"	W077°10’33.32"	0.7164	0.002

HAGS 54	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°23’21.68"	W077°10’35.90"	0.7159	0.002
HAGS 55	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°23’21.2"	W077°10’31.7"	0.7164	0.003
HAGS 56	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°23’20.2"	W077°10’32.9"	0.7151	0.002
HAGS 57	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°23.329"	W077°10.567"	0.7157	0.002
HAGS 58	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°23’22.2"	W077°10’32.8"	0.7159	0.002
HAGS 59	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°23’22.2"	W077°10’33.2"	0.7161	0.001
Mean						**0.7162**	**0.002**
HAGS 60	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°2106.9"	W077°11’23.0"	0.7142	0.002
HAGS 61	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°21’08.2"	W077°11’20.2"	0.7133	0.002
HAGS 62	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°21’05.4"	W077°11’15.9"	0.7139	0.002
HAGS 63	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°21’05.8"	W077°11’14.7"	0.7141	0.001
HAGS 64	Bulimulidae	Mesozoic	Oyón, Huaalhuani Murco	S 09°21’07.27"	W077°11’17.47"	0.7128	0.002
HAGS 65	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°21’05.2"	W077°11’18.5"	0.7134	0.002
HAGS 66	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°21’07.1"	W077°11’12.6"	0.7142	0.003
HAGS 67	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°21’07.37"	W077°11’15.74"	0.7138	0.002
HAGS 68	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°21’03.28"	W077°11’15.24"	0.7141	0.001
HAGS 69	*Stipa ichu*	Mesozoic	Oyón, Huaalhuani Murco	S 09°21’03.10"	W077°11’20.21"	0.7134	0.002
Mean						**0.7137**	**0.002**
HAGS 70	Bulimulidae	Mesozoic	Inca, Pariahuanca, chúlec Pariatambo	S 09°21'2.44 "	W077°5'35.66"	0.7123	0.001
HAGS 71	Bulimulidae	Mesozoic	Inca, Pariahuanca, chúlec Pariatambo	S 09°21'39.05"	W077°5'31.39"	0.7121	0.003

HAGS 72	*Stipa ichu*	Mesozoic	Inca, Pariahuanca, chúlec Pariatambo	S 09°21'23.49"	W077°5'14.96"	0.7129	0.002
HAGS 73	*Stipa ichu*	Mesozoic	Inca, Pariahuanca, chúlec Pariatambo	S 09°21'7.91"	W077°5'59.54"	0.7121	0.002
HAGS 74	*stipa ichu*	Mesozoic	Inca, Pariahuanca, chúlec Pariatambo	S 09°21'42.17"	W077°5'40.25"	0.7126	0.002
Mean						**0.7124**	**0.002**
HAGS 75	*Stipa ichu*	Paleozoic	Pucará Group	S 09°14'10.39 "	W076°54'43.81"	0.7163	0.002
HAGS 76	*Stipa ichu*	Paleozoic	Pucará Group	S 09°14'15.54 "	W076°55'1.53"	0.7154	0.001
HAGS 77	*Stipa ichu*	Paleozoic	Pucará Group	S 09°14'5.98"	W076°55'15.38"	0.7158	0.002
Mean						**0.7158**	**0.002**
HAGS 78	Bulimulidae	Neoproterozoic	Marañón Group	S 09°14’25.92"	W076°54’17.51"	0.7198	0.002
HAGS 79	Bulimulidae	Neoproterozoic	Marañón Group	S 09°14’28.26"	W076°54’18.67"	0.7207	0.002
HAGS 80	Bulimulidae	Neoproterozoic	Marañón Group	S 09°14’29.93"	W076°54’16.72"	0.7212	0.001
HAGS 81	Bulimulidae	Neoproterozoic	Marañón Group	S 09°14’28.10"	W076°54’14.52"	0.7214	0.002
HAGS 82	Bulimulidae	Neoproterozoic	Marañón Group	S 09°14’30.79"	W076°54’12.78"	0.7202	0.003
HAGS 83	*Stipa ichu*	Neoproterozoic	Marañón Group	S 09°14’33.0"	W076°54’09.6"	0.7159	0.002
HAGS 84	*Stipa ichu*	Neoproterozoic	Marañón Group	S 09°14’29.7"	W076°54’14.9"	0.7197	0.004
HAGS 85	*Stipa ichu*	Neoproterozoic	Marañón Group	S 09°14’29.4"	W076°54’18.2"	0.7215	0.003
HAGS 86	*Stipa ichu*	Neoproterozoic	Marañón Group	S 09°14’29.1"	W076°54’19.6"	0.7187	0.002
HAGS 87	*Stipa ichu*	Neoproterozoic	Marañón Group	S 09°14’32.20"	W076°54’10.85"	0.7208	0.001
Mean		Neoproterozoic				**0.7200**	**0.002**
HAGS 88	Bulimulidae	Neoproterozoic	Marañón Group	S 09°14' 8.26"	W076°57'45.70"	0.7179	0.002
HAGS 89	Bulimulidae	Neoproterozoic	Marañón Group	S 09°13'56.75"	W076°57'43.34"	0.7187	0.001
HAGS 90	*Stipa ichu*	Neoproterozoic	Marañón Group	S 09°14' 5.09"	W076°57'59.32"	0.7192	0.002
HAGS 91	*Stipa ichu*	Neoproterozoic	Marañón Group	S 09°13'54.91 "	W076°58'3.08"	0.7194	0.002
HAGS 92	*Stipa ichu*	Neoproterozoic	Marañón Group	S 09°14' 12.27"	W076°58'1.29"	0.7184	0.001
Mean		Neoproterozoic				**0.7187**	**0.002**
HAGS 93	Bulimulidae	Neoproterozoic	Marañón Group	S 09°0'6.11"	W077°1'2.29"	0.7208	0.002

HAGS 94	Bulimulidae	Neo-proterozoic	Marañón Group	S 09˚0'5.07 "	W077˚1'32.08"	0.7206	0.002
HAGS 95	Bulimulidae	Neo-proterozoic	Marañón Group	S 09˚0'46.10 "	W077˚0'59.93"	0.7203	0.001
HAGS 96	Bulimulidae	Neo-proterozoic	Marañón Group	S 09˚0'22.11"	W077˚0'45.79."	0.7212	0.002
HAGS 97	Bulimulidae	Neo-proterozoic	Marañón Group	S 09˚0'13.72"	W077˚0'29.21"	0.7205	0.001
HAGS 98	*Stipa ichu*	Neo-proterozoic	Marañón Group	S 09˚0'3.83"	W077˚1'22.60"	0.7206	0.002
HAGS 99	*Stipa ichu*	Neo-proterozoic	Marañón Group	S 09˚0'37.89 "	W077˚0'54.38"	0.7196	0.002
HAGS 100	*Stipa ichu*	Neo-proterozoic	Marañón Group	S 09˚0'37.57 "	W077˚0'54.78"	0.7198	0.002
Mean						**0.7205**	**0.020**

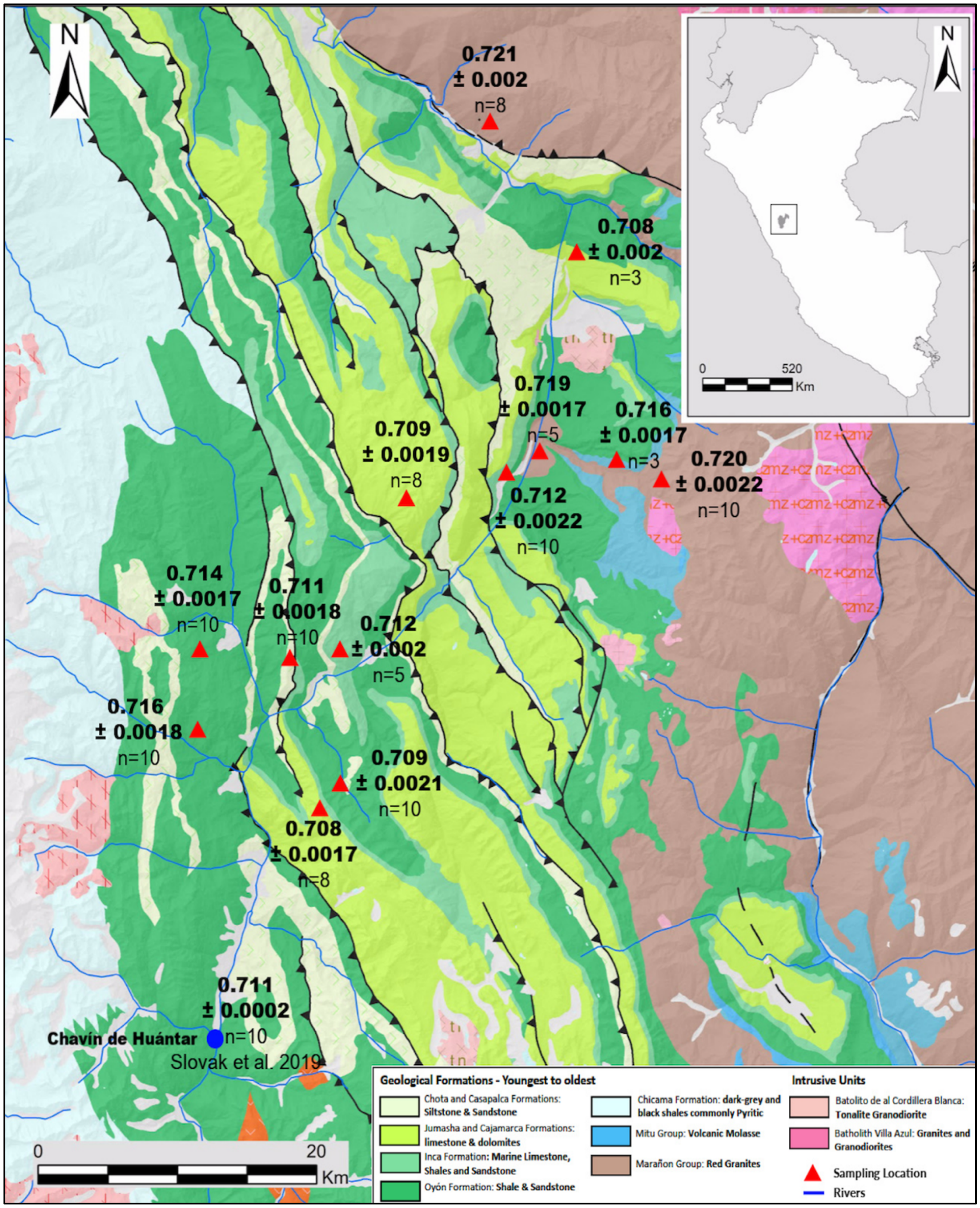

Fig 5.2: $^{87}Sr/^{86}Sr$ isoscape of the Callejón de Conchucos in the north-central Peruvian highlands. Environmental reference samples include modern grass (*Stipa ichu)* and snail shells. Mean $^{87}Sr/^{86}Sr$ values were calculated for each geological formation and are presented along with mean standard error.

5.6 Discussion

5.6.1 The use of $^{87}Sr/^{86}Sr$ isoscapes - What does it mean to be a "local?"

Within relatively short distances between sampling locations, we documented considerable differences in mean ^{87}Sr/^{86}Sr values per geological unit that range from as low as 0.708 all the way up to 0.721 within just 10km distance, as in our two most northern sampling locations (Fig 5.2). This suggests that in geological settings like this, farming, animal husbandry and hunting would probably result in the utilization of several larger geological units with distinct geological ages and mean ^{87}Sr/^{86}Sr values. We can extend this statement to other locations within our study region in the Callejón de Conchucos. This finding has considerable implications for archaeological scholars interested in understanding past human mobility working not only in this specific region, but throughout the Andes.

The analysis of ^{87}Sr/^{86}Sr values in human skeletal remains is an extremely powerful tool that has the potential to elucidate aspects of human behavior otherwise difficult to directly observe. Despite these potential research benefits, the interpretation of ^{87}Sr/^{86}Sr data is not always straightforward. Individuals with ^{87}Sr/^{86}Sr values outside the range of potential ^{87}Sr/^{86}Sr values of a given site are commonly defined to be of non-local origin, whereas those with ^{87}Sr/^{86}Sr values matching those of the immediate vicinity of the site are considered residents to that site. Our data shows that locally living individuals can potentially have a range of sources of ^{87}Sr/^{86}Sr values within a discrete area, depending on where they farmed their plants and produced their animal food. We argue that an individual can only be considered as being of non-local origin if the $^{87}Sr/^{86}Sr$ values measured in enamel of early forming teeth fall outside of the local $^{87}Sr/^{86}Sr$ range, as defined by a $^{87}Sr/^{86}Sr$ isoscape based on environmental samples. If the $^{87}Sr/^{86}Sr$ values measured in enamel are represented in the area around an archaeological site, they should be considered potentially local.

In the high-altitude Andes specifically, people have always been mobile and frequently moved up, down and across vertically stacked landscapes in order to exploit different production zones at different elevations [129-134]. In the highland Andes, archaeological sites are frequently located along these ecological boundaries, allowing their inhabitants to exploit multiple ecological zones that cross different geological formations [70, 135-142]. This adaptive strategy allowed groups to actively access key resources from different vertically stacked environmental zones. This may have been achieved by one community having satellites in different ecological zones, but that were linked to each other through exchange and/or kinship relationships, in other words a ‘vertical archipelago’ [70, 129, 143-145]; or mobile groups who camped at different zones to access resources seasonally [70, 131, 133, 146].

Because the $^{87}Sr/^{86}Sr$ value of a given tissue (i.e., bone or tooth enamel) is a composite average of all the bioavailable $^{87}Sr/^{86}Sr$ ingested over the duration of that tissues formation [13, 46, 147] the extent of landscape-use related mobility must be considered, especially within regions that are geologically complex like the Andes. If enamel of late forming teeth is used and individuals are indeed encountering dietary items from differing geological formations regularly, their ^{87}Sr/^{86}Sr values will be a mix of all Sr consumed. For example, if an adult individual's ^{87}Sr/^{86}Sr value does not fit within the bioavailable ^{87}Sr/^{86}Sr range of a given site that does not necessarily mean this person should be considered non-local, but may indicate a more complicated daily or seasonal mobility and/or movements occurring across multiple years. It is for this reason that ^{87}Sr/^{86}Sr studies should always be combined with archaeological data to allow for a more holistic interpretation of the results. This study raises the question of how-to best use ^{87}Sr/^{86}Sr studies to interpret the range of variation found within individuals from within the Callejón de Conchucos and what it means to be classified as local vs. non-local.

5.6.2 Comparing a pan-Andean isoscape to regionally specific ^{87}Sr/^{86}Sr studies

In a new, unpublished study, Scaffidi and Knudson [in press, 16] present a pan-Andean isoscape that uses geostatatical modeling of all past ^{87}Sr/^{86}Sr isotope studies in Peru to extrapolate the extent of ^{87}Sr/^{86}Sr isotope variation in the country. This study represents the first attempt to produce a pan-Andean isoscape for the purpose of documenting past mobility. While this modelling approach can be extremely useful for future case studies in Peru, it at the same time relies on the accuracy and density of reference ^{87}Sr/^{86}Sr data. As we have discussed above, there are limitations to some of the published ^{87}Sr/^{86}Sr data available for such spatial models. Thus far, the majority of ^{87}Sr/^{86}Sr studies within Peru have taken place either along the Pacific coast or in Southern Andes particularly along the western slopes, with very few studies in the eastern highlands (Table 5.1; Fig 5.2; [e.g., 31, 32, 34, 35, 50-52, 55, 58, 67, 148]). Because of this, the model created by Scaffidi and Knudson [in press, 16], is biased towards larger datasets available from these geographic regions, whereas underrepresented regions appear as isotopic “blind spots”. This means in this new isoscape, regions with little to no $^{87}Sr/^{86}Sr$ reference data are being presented as geologically and isotopically uniform. This affects the projection of $^{87}Sr/^{86}Sr$ values for the Callejón de Conchucos region, for which we here present highly variable environmental data.

The new $^{87}Sr/^{86}Sr$ isoscape [16] shows a general pattern of a west to east gradient of less to more radiogenic values, with lower $^{87}Sr/^{86}Sr$ values along the coast (i.e., 0.7038-0.70550 coastal) and generally higher values moving towards the east (0.7177-0.7239). While on a gross scale and over large distances this distinction is accurate, it appears to oversimplify the $^{87}Sr/^{86}Sr$ variation detectable on a smaller regional scale. Our study suggests that there is considerable geological variation within the Callejón de Conchucos, a small region totaling only 0.4% of Peru, but also has more extensive isotopic variation than initially estimated, including relatively low and relatively radiogenic $^{87}Sr/^{86}Sr$ values (0.708-0.722).

The geology of the Andes is comprised of closely stacked geological formations that run in parallel from north to south. Our study demonstrates that because each of these geological formations is of different geologic age, there are differing $^{87}Sr/^{86}Sr$ values represented all within close proximity to one another. Differing from the pan-Andean isoscape created by Scaffidi and Knudson [16], in our localized region there does not appear to be a west-east trend in $^{87}Sr/^{86}Sr$ values, with our lowest $^{87}Sr/^{86}Sr$ value (0.708) falling in Jumasha and Cajamarca formations running in between higher $^{87}Sr/^{86}Sr$ values (0.714-0.716 west; 0.721-0.722 east).

The entire range of documented $^{87}Sr/^{86}Sr$ values in archaeological Andean samples is 0.7038-0.7234, which is just as broad as reported globally [13]. Interestingly, the heterogeneity of $^{87}Sr/^{86}Sr$ values in the Callejón de Conchucos isocape we report here is not much lower than that (0.708-0.722). Based on our data, we can predict with confidence that this degree of $^{87}Sr/^{86}Sr$ variation will be present throughout the Andes. It is therefore necessary to continue to conduct regional $^{87}Sr/^{86}Sr$ studies to add to and refine the data resolution of this innovative pan-Andean isoscape.

5.6.3 Mobility on a pan-Andean vs. regional scale: A reinterpretation of the provenience of individuals from the site Chavín de Huantar

A recent study by Slovak and colleagues [36] reported the first $^{87}Sr/^{86}Sr$ signatures from five human Recuay individuals (ca. 1-700 B.C.E.) buried at the Peruvian highland ceremonial center of Chavín de Huántar (3180 masl), located within the Callejón de Conchucos (Fig 5.2). To establish a local bioavailable $^{87}Sr/^{86}Sr$ range, several soil, animal and plant samples collected from only directly within the ceremonial center (~2ha) were analyzed (Slovak et al. 2018). Based on these reference samples, three Chavín human individuals were classified to be of local origin (CdH_38, 39, 40 $^{87}Sr/^{86}Sr$ = 0.7111-0.7113), whereas two others with $^{87}Sr/^{86}Sr$ values outside the calculated bioavailable range (CdH_36 $^{87}Sr/^{86}Sr$ = 0.708;

CdH_37 $^{87}Sr/^{86}Sr$ = 0.706) (based on a mean ±2 SD) and were considered to be of non-local origin. Based on our study, we suggest that sample size and reference sampling locations were insufficient to accurately determine the diversity of potential regional $^{87}Sr/^{86}Sr$ values surrounding the site of Chavín de Huántar.

This study used published $^{87}Sr/^{86}Sr$ data from throughout the Andes to present some conclusions about the potential origins of the two individuals classified as non-local. Potential regions of origin range from the central coast to the Atacama Desert. However, because this study only referred to environmental samples from within the archaeological site, the possibility of nearby regions with similar $^{87}Sr/^{86}Sr$ values was not evaluated. Based on our data, we propose that at least for individual CdH_36 with a $^{87}Sr/^{86}Sr$ value of 0.708 the actual provenience could well lie within the Callejón de Conchucos region. $^{87}Sr/^{86}Sr$ values similar to this individual can be found in the vicinity of Chavín de Huántar, for example, within the Jumasha and Canjamarca formations; only 10 km away from Chavin, we find $^{87}Sr/^{86}Sr$ values of 0.708 ±0.0017 (Fig 5.2). We conclude that it is possible that this individual had a life history background in our study region and moved to Chavín de Huántar after early childhood (premolars and second molars were used).

5.7 Conclusion

The results of this study build upon the initial innovative and groundbreaking work of previous $^{87}Sr/^{86}Sr$ isotope studies within Peru. The challenge with $^{87}Sr/^{86}Sr$ data and its usefulness in making determinations about past human life lies in its interpretation and the quality of reference data. In most small-scale $^{87}Sr/^{86}Sr$ studies some conclusions about the individuals under investigation can be reached, but the accuracy of these interpretations can be challenged. We assert that in order to refine our ability to interpret the results of $^{87}Sr/^{86}Sr$ studies, a more comprehensive method for analysis includes a large-scale study of all accessible geological formations and the isotopic variation within these geologies. This allows a researcher to examine a greater range of possibilities for why an individual may have a $^{87}Sr/^{86}Sr$ value outside the expected local range.

We argue the necessity of continuing to document the extent of $^{87}Sr/^{86}Sr$ variation in archaeological work and develop regionally specific $^{87}Sr/^{86}Sr$ isoscapes. It is only with this regionally specific data that a pan-Andean $^{87}Sr/^{86}Sr$ isocape will have the data resolution necessary to accurately extrapolate $^{87}Sr/^{86}Sr$ values for regions not yet fully documented.

Acknowledgements

We thank Terry Blackburn and the W.M. Keck Laboratory Staff for their continued support with isotope analysis. We also thank Rachel Johnson and Alana Garvey for their contributions to sample collection in the field. Import permits for all plants and snail shells were granted by the United States Department of Agriculture, Animal and Plant Health Inspection Service (PCIP-18-00364).

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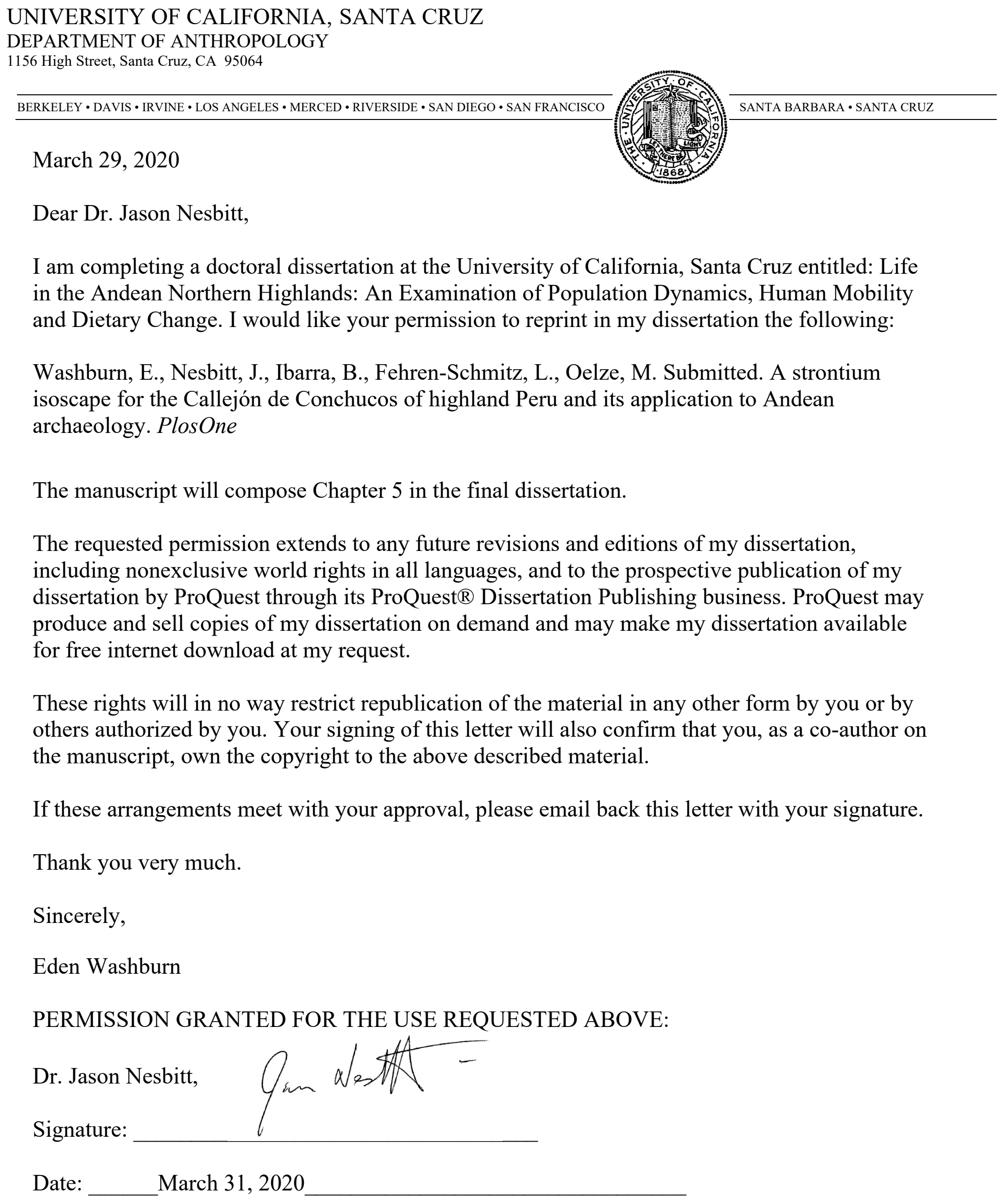

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CHAPTER 6

A multi-isotope approach to the study of residential mobility and diet in the Late Intermediate Period in highland Ancash, Peru

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Note: This paper in preparation for submission to Journal of Archaeological Science. Permission to include this article as a chapter of this dissertation was granted by all co-authors (see signed permission letters at the end of this chapter)

Abstract

The Late Intermediate Period (or LIP, c. AD 1000-1450) was a time of cultural change and reorganization in the Peruvian highlands. During this time, interpersonal violence increased and settlements were placed in defensible locations at high elevations. Coinciding with these cultural disruptions were widespread shifts in mortuary practices in which the deceased were buried in above ground tombs known as chullpas, and in caves. In this study, we present a multi-isotopic approach aimed at understanding that nature of human diet and mobility during the LIP in the Conchucos region of north-central Peru. To address these topics, carbon and nitrogen ($\delta^{13}C$ and $\delta^{15}N$) and strontium ($^{87}Sr/^{86}Sr$) isotope analysis was applied to human skeletal remains (n=101) from burials at the sites of Marcajirca (n=66), Jato Viejo (n=9), and Ushcugaga (n=26). At all three sites, dietary mixing models of the $\delta^{13}C$ and $\delta^{15}N$ data suggested an agrarian human diet based largely on maize as well as some C_3 plants, camelids and guinea pig. $^{87}Sr/^{86}Sr$ data varied between and within sites, yet indicated mobility was limited to the Conchucos region and that the burials in open tombs can be asigned to specific, extended kin groups. We conclude that during the LIP in the Conchucos groups were not isolated, people adapted, created exchange networks, and/or took advantage of their natural surroundings in order to access subsitence resources.

Key Words: Carbon, Nitrogen, Strontium, mortuary practices

6.1 Introduction

The Late Intermediate Period (c. AD 1000-1450) was a time when much of the Peruvian highlands entered a period of political fragmentation following the collapse of the Wari polity of the Middle Horizon (c. AD 700-1000) (Covey 2008; Parsons and Hastings 1988). These cultural transformations are recognized by higher frequencies of skeletal evidence for interpersonal violence, and the relocation of large settlements into defensive locations at higher elevations (~above 3,500 masl) (Álvarez and Greco 2018; Arkush 2008, 2011; Arkush and Stanish 2005; Arkush and Tung 2013; Bauer and Kellett 2010; Bauer et al. 2010; Ibarra 2020; Jolly and Kurin 2017; Kellett 2010; Lofaro et al. 2018; Kurin 2013; Meddens and Branch 2010; Torres-Rouff et al. 2005; Tung 2008; Tung et al. 2016).

Economic factors also account for the LIP movement of settlement into the high-altitude *puna* grassland (3,600-4,500 masl) (e.g. Bauer and Kellett 2010; Parsons et al. 1997), a landscape conducive to agro-pastoral practices, including herding of domesticated camelids (llamas and alpaca) and cultivation of grains and tubers. At the same time, sites were also positioned at altitudes exceeding the limits of other crops such as maize. These limitations necessitated the movement of people, or the establishment of exchange relationships with the inhabitants of different ecological production zones, in order to access lower-elevation crops.

Coinciding with the social and economic transformations of the LIP were changes in mortuary practices. In particular, there was a widespread shift towards above- ground masonry chamber tombs, known as chullpas, and cave burials. Both kinds of tombs frequently contained the burials of numerous individuals that were interred over multiple generations. It is generally thought that chullpa and caves contained individuals related through kinship, and therefore identified as a material correlate for ancestor worship as a structuring ethnic organizing principal (Hyslop 1977; Ibarra 2020; Isbell 1997; Mantha 2009; Nielsen 2008; Velasco 2014, 2016).

In this paper, we employ a multi-isotopic approach to evaluate the life history of individuls buried primarily in chullpa and caves from the cemeteries of Marcajirca, Ushcugaga, and Jato Viejo in the Conchucos region of highland Ancash in north-central Peru. (FIgure 6.1). Specifically, we focus on carbon, nitrogen (δ^{13}C and δ^{15}N) and strontium (^{87}Sr/^{86}Sr) isotope data measured in human skeletal remains (n=101) from each of these sites (Marcajirca n=66; Jato Viejo n=9; Ushcugaga n=25) to evaluate diet and residential mobility. Our results indicate that the inhabitants of these sites maintained a diet in which C_4 plants (probably maize) was an important component of the diet, along with animal protein from camelids. Sr analysis demonstrates that the majority of individuals found in each site were from the local Conchucos region.

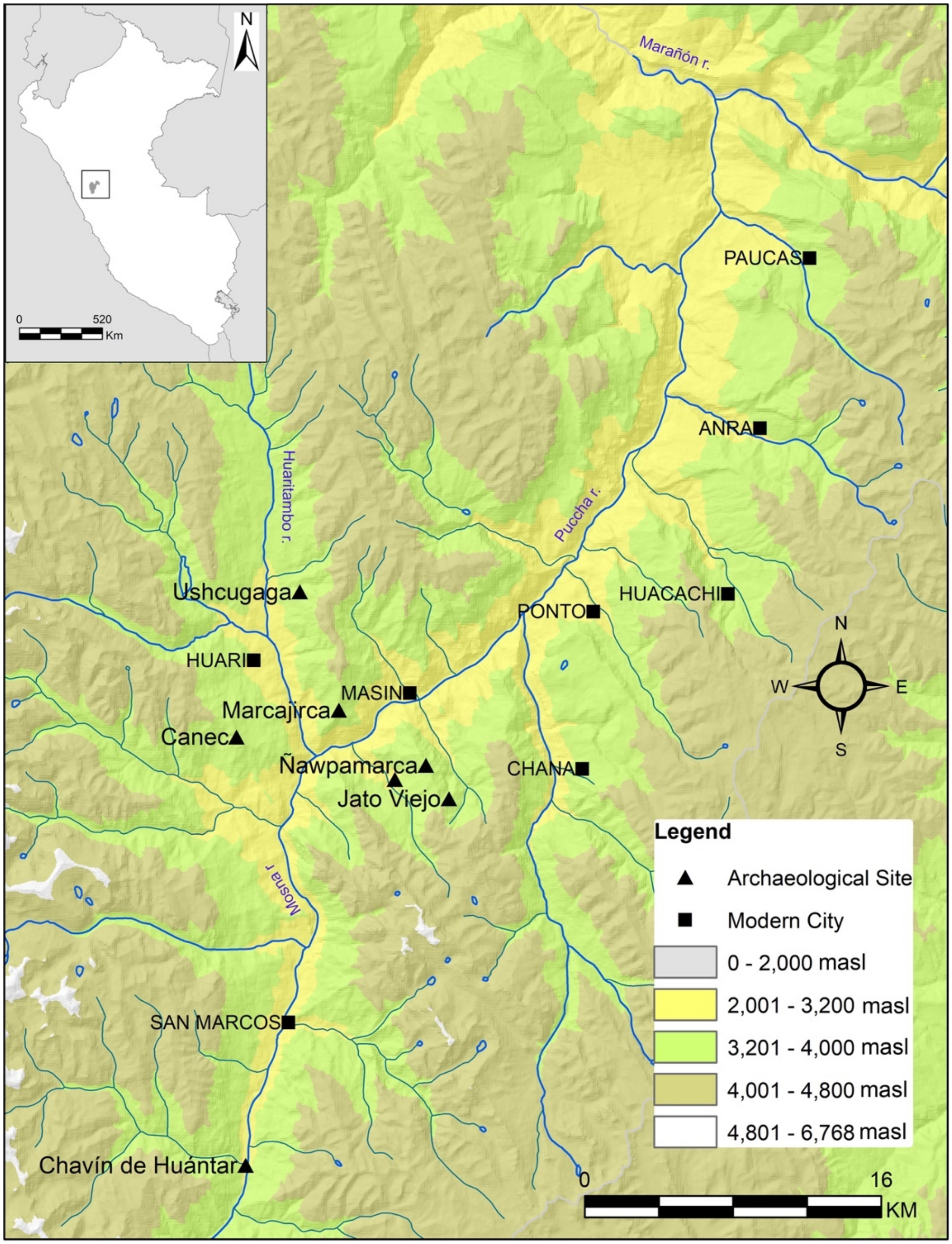

Figure 6.1: Map of the of the Conchucos region with the location of locations mentioned.

6.2 Background

6.2.1 Stable Carbon and Nitrogen Isotope Analysis

Stable carbon and nitrogen isotope analysis of an organism's tissues reflect the types of food resources consumed during life (Ambrose 1990; DeNiro and Epstein 1978, 1981; DeNiro and Schoeniger 1983; Keegan and DeNiro 1988; Schoeninger et al. 1983; Tieszen and Fagre 1993; Walker and DeNiro 1986). A fundamental source of variation in values of $\delta^{13}C$ in terrestrial food webs stems from differences in the photosynthetic pathways of plants (Finucane et al. 2006; Schoeninger and Moore 1992). Most plants found in the Central Andes utilize the Calvin Cycle (C_3) (i.e. potatoes (*Solanum* sp.) and other tubers, quinoa (*Chenopodium quinoa*), tarwi (*Lupinus mutabilis*), and squash (*Cucurbita* sp.), at an average $\delta^{13}C$ value of -26.5‰ (Tieszen and Fagre 1993; van der Merwe and Medina 1989). Plants relying on the Hatch-Slack pathway (C_4) include many domesticates such as maize (*Zea mays*), millet, and amaranthus including kiwicha (*Amaranthus caudatus*), with an average $\delta^{13}C$ value of -12.5‰ (Finucane et al. 2006; Hatch and Slack 1966; Hatch et al. 1967; van der Merwe and Medina 1989).

Analysis of $\delta^{15}N$ values discriminates between leguminous (N-fixing) plants, non-leguminous plants, and higher tropic level foods such as animal protein (Schoeninger and DeNiro 1984; Walker and DeNiro 1986). With each step up the food chain there is a tropic level ~2-5‰ increase in the $\delta^{15}N$ values (Schoeninger and DeNiro 1984), and as such, the $\delta^{15}N$ values can be used to reconstruct food webs

(Ambrose and DeNiro 1986; Minagawa and Wada 1984; Schoeller 1999; Schoeninger and DeNiro 1984).

6.2.2 *^{87}Sr/^{86}Sr Analysis and Human Mobility*

The analysis of ^{87}Sr/^{86}Sr isotopes in skeletal tissue is an established method for detecting mobility in both humans and animals (Bentley et al. 2002; Price et al. 2002; Price et al. 2004; Washburn et al. in review). The ^{87}Sr/^{86}Sr signature of a given location is primarily determined by the age of the underlying bedrock and its rubidium (Rb) content, as the radiogenic ^{87}Sr forms through the radioactive decay of ^{87}Rb. Strontium enters the biosphere through uptake from the substrate by plants and is passed along the food chain into, for example, the tissues of both animals and humans. The chemical behavior and similar atomic mass of strontium and calcium (Ca) allows strontium to substitute for Ca, in the cellular structures of plants, or in the hydroxyapatite of both bone and tooth enamel. The isotopic composition of strontium does not change or fractionate during biological processes and as a result, the ^{87}Sr/^{86}Sr values measured in flora and fauna vary based on the age of the immediate bedrock (Bentley 2006; Graustein 1989; Price et al. 2002).

Bioavailable strontium (^{87}Sr/^{86}Sr that makes its way into the foodweb) often differs from geologically available strontium (Budd et al. 2000; Evans et al. 2010; Price et al. 2002); thus, it is important to reconstruct the bioavailable ^{87}Sr/^{86}Sr of a given region by sampling local plants, soil or faunal remains (Price et al. 2002). Assuming the consumption of only locally sourced food and water, bioavailable

$^{87}Sr/^{86}Sr$ values will primarily reflect the signature of the immediate geological location in which an individual lived during the sampled tissues' formation. This study utilizes bioavailable $^{87}Sr/^{86}Sr$ data from a regional isoscape constructed for the Conchucos region to estimate the bioavailable $^{87}Sr/^{86}Sr$ range for each site, as well as the surrounding geological formations (Washburn et al. in review).

6.3 Materials

The study area is in the Puccha basin, which is composed of the Huaritambo, Mosna and Puccha rivers. These river systems form part of the larger Conchucos region, an intermontane valley system situated on the eastern side of the Cordillera Blanca in highland Ancash. During the LIP, most archaeological sites are positioned at elevations above 3,700 masl (Ibarra 2020). Importantly, there are key transformations in the treatment of the dead, including the interment of individuals in chullpas, caves, and rare interments underneath houses (Ibarra 2020). In the case of chullpas and caves, most had multiple individuals that were buried at different points in time. These burials were originally wrapped bundles, which after deteriorating over time led to the commingled remains of different individuals. In this study, we focus on tombs from three archaeological sites that were radiocarbon dated to the 14th and 15th centuries AD: Marcajirca, Ushcugaga, and Jato Viejo (see Supplementary information S6.1; Table S6.3; Figure S6.3).

6.3.1. Marcajirca

Marcajirca is located at 3,750 masl, approximately 6km east of the modern-day city of Huari. It is a large settlement composed of three sectors: residential, funeral and ceremonial, covering an area of over 40 hectares (Figure S6.1; S2). Radiocarbon dates suggest that the site was occupied between ca. AD 1040 and 1640 (Ibarra 2020), with primary occupation during the LIP . The residential sector consists of a cluster of approximately 50 houses, with an estimated population of at least 300 residents during the LIP occupation (Ibarra 2009, 2020).

Marcajirca also has a major mortuary component. A total of 37 chullpas were identified at the site. In addition, Marcajirca has 21 burial caves, and two underground burials situated inside of abandoned houses. Through the analysis of six *chullpas* and caves, it is estimated that *chullpas* held between 36 and 77 individuals, while caves had between 9 and 72 (Supplementary information S6.1; Table S6.1) (Ibarra 2009, 2020).

Skeletal analysis revealed interesting and enlightening observations about the human remains from Marcajirca. First, it is apparent that the bodies were not all interred at the same time, but that tombs were accessed and re-accessed over time. Second, there was a relatively high frequency of cranial trauma that appears to be related to interpersonal violence. Archaeological testing of four *chullpas* yielded 24 adult crania, of which eight (33%; 5 male, 1 possible female, 2 indeterminate sex) demonstrated healed or unhealed fractures (Titelbaum et al. 2013).

6.3.2 Jato Viejo

Jato Viejo is a cave site that contains human burials, yet does not have an associated residential site (Figure S6.2). The closest coeval settlement is Ñawpamarca de Huachis located about 2 km to the west. Situated at an elevation of 3,865 masl, Jato Viejo consists of 14 burial caves scattered along a vertical outcrop. Cave 1 contained skulls representing at least 12 individuals, while the other caves only yielded evidence of scattered bone. Samples for the current analysis were collected from Cave 1 (Supplementary information S6.1; Table S6.1).

6.3.3 Ushcugaga

Ushcugaga is a cemetery located above the Huaritambo River at an altitude of 3,500 masl, and consists of a large field of boulders covering an area of 1.2 hectares (Figure S6.2). Twenty-one caves created by overlapping boulders were identified, and human remains were present in all of the caves except for one. Detailed field analysis of the human remains determined the presence of multiple individuals, including adults and sub-adultsin each of the caves (MNI 1-7; see Supplementary information S6.1; Table S6.1).

6.3.4 Human Skeletal Material

A total of 101 individual human dental samples (M_1, M_2, or M_3) were collected from Marcajirca, Ushcugaga and Jato Viejo (Table S6.4). Due to the high degree of commingled remains found at all three archaeological sites, teeth were removed from the skull directly, thus ensuring all teeth sampled came from different individuals. Dentine from each tooth was used for $\delta^{13}C$ and $\delta^{15}N$ isotope analysis, while a subset of enamel samples (n=53 individuals) was used for $^{87}Sr/^{86}Sr$.

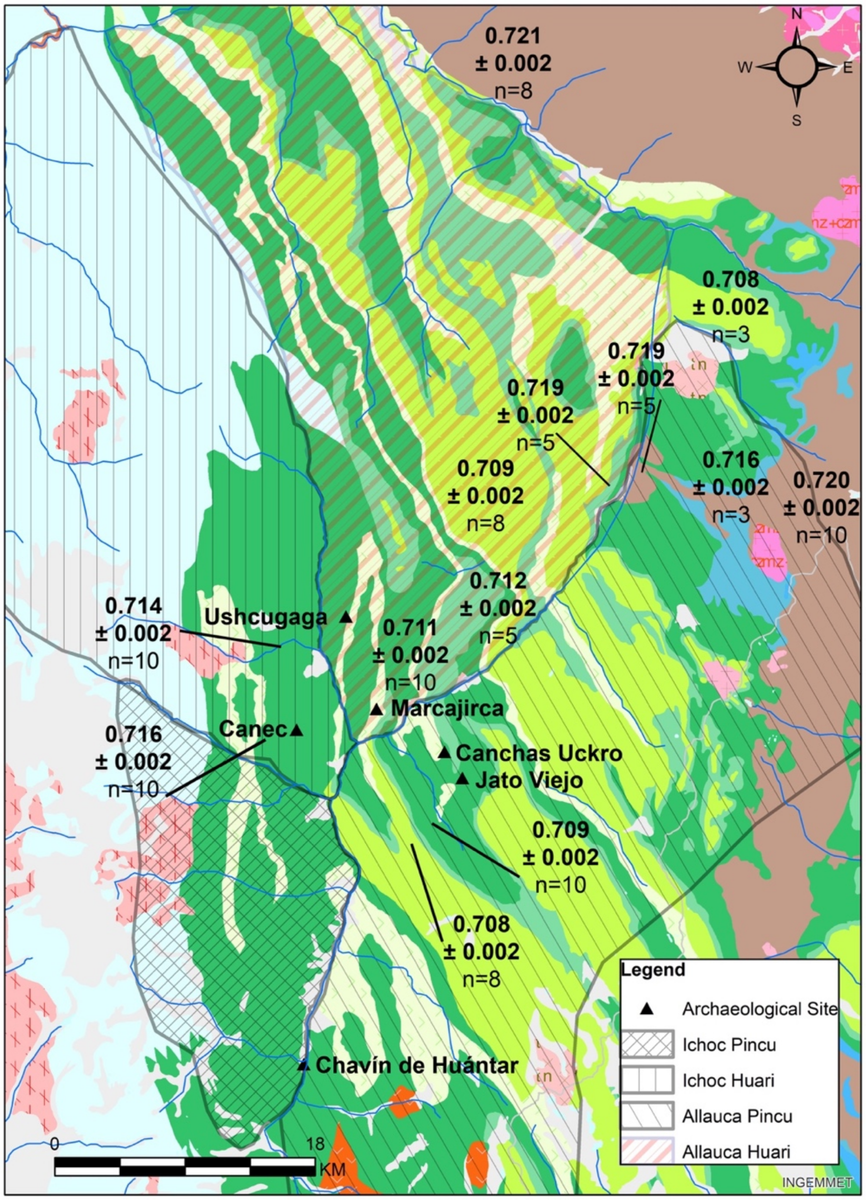

Figure 6.2: $^{87}Sr/^{86}Sr$ isoscape of the Conchucos region in the north-central Peruvian highlands. Environmental reference samples include modern grass (*Stipa ichu*) and snail shells. Mean $^{87}Sr/^{86}Sr$ values were calculated for each geological formation and are presented along with mean standard error (%) (Washurn et al. in review).

6.3.3 $\delta^{13}C$ and $\delta^{15}N$ Dietary Reference Material

Isotope data from possible dietary resources was compiled from the relevant literature (DeNiro and Hastorf 1985; Finucane et al. 2006; Turner et al. 2010; Washburn et al. 2020). Data was limited to food types found in highland sites with similar ecological conditions as in the Puccha River Valley (Washburn et al. 2020). In our study, only modern domestic plant sample data were included from DeNiro and colleagues (1985), and as a result are possibly exposed to at least minimal amounts of either manuring or modern fertilizer. The effect of manuring on plants can result in substantial changes in $\delta^{15}N$ values, while modern fertilizer can either raise or lower $\delta^{15}N$ values (DeNiro and Hastorf 1985; Szpak et al. 2012). There are, however, no statistical or analytical means of detecting this in our data set. As a result, we consider the plants included in our study to represent differing levels of manuring and fertilization.

To eliminate overlap, dietary meat sources were split into groups based on the animal's $\delta^{13}C$ value (Table S6.2). Grazers represent animals (i.e. camelids and white-tailed deer) with $\delta^{13}C$ values indicative of a C_3 plant diet, while foddered camelids were identified by Finucane and colleagues (2006) as being fed C_4 plants (maize). Guinea pigs typically have diets that reflect the isotopic signature of the food provided to them, and may therefore share similar isotope values with humans (Finucane et al. 2006; Washburn et al. 2020). As a result, if combined into one group guinea pig $\delta^{13}C$ values would result in large standard deviation (mean $\delta^{13}C$ value -10.9‰ ±3.7). It is for this reason guinea pig isotope values were divided into two groups (i.e. Group 1: mixed plant diet [-18.6‰ to -14.6‰] and Group 2: C_4 plant diet [-12.6‰ to -7.0‰]).

6.4 Methods

We radiocarbon dated eight human bone/tooth samples to establish absolute dates for different burial contexts used in this study (see Supplementary information S6.1; S6.2). Further, sex was estimated using morphological observations of the skull (Buikstra and Ubelaker 1994; see Supplementary information S6.1). For 40 of the 101 indviduals the bioarchaeological assessment of sex was tested using aDNA, which corroborated the bioarchaeological sex estimation for 30 individuals; 2 indivdiuals were shown to have been incorrectly sexed using morphological observation, and the sex of 8 individuals could not be established using aDNA (see Supplementary information S6.1; Table S6.5).

6.4.1 Carbon and Nitrogen Isotope Analysis

All dentine samples were prepared following a modified protocol by Richards and Hedges (1999). Samples were demineralized using 0.5M HCL, rinsed 3x with dH_2O. pH≈3 water was added to each sample and samples were placed in heater blocks at 70°C for 48 hours. Following collagen solubilization, remaining particles were filtered using eeze^{TM} filters (60-90μm). Samples were then subjected to ultracentrifugation using AMICON Ultra-4 filters with a 30 kDa cutoff and freeze dried. Only the large fraction of collagen (i.e. >30kDa) was analyzed.

Collagen samples were weighed, encapsulated in tin, and analyzed for carbon (C) and nitrogen (N) stable isotope ratios by the UC Santa Cruz Stable Isotope Laboratory using a CE Instruments NC2500 elemental analyzer coupled to a Thermo Finnigan DELTAplus XP isotope ratio mass spectrometer via a Thermo-Finnagan ConFlo III. Duplicates were performed on every 5th sample to substantiate measurement accuracy. All measurements have been corrected to VPDB (Vienna PeeDee Belemnite) for $\delta^{13}C$ and AIR for $\delta^{15}N$ against an in-house gelatin standard reference material (PUGEL), which is extensively calibrated against international reference materials. Measurements were corrected for size, blank-mixing and drift effects. An externally calibrated Acetanilide standard reference material purchased from Dr. Arndt Schimmelmann of Indiana University was measured 'as sample' for independent quality control. Typical reproducibility of replicates is significantly better than 0.1‰ for $\delta^{13}C$ and 0.2‰ for $\delta^{15}N$.

6.4.2 $^{87}Sr/^{86}Sr$ Analysis

Human dental enamel samples were mechanically cleaned and then removed from the rest of the tooth using a dental drill. The separated tooth enamel was then placed in ultrapure acetone and rinsed in an ultrasonic bath from 15 minutes to remove any potential remaining surface contaminants. Enamel samples were further processed in the UC Santa Cruz W.M. Keck Isotope Laboratory clean room, where 10-15mg of enamel was weighed into clean Teflon beakers and digested. Following the protocol outline in Washburn et al. in review, enamel samples were subjected to column chromatrogrpahy using Sr-spec™ resin and analyzed using a Thermo Finnigan Neptune™ MC-ICP-MS.

In addition, this study utilizes the reference data collected from an extensive isoscape mapping project of the Conchucos region, in which the bioavailable $^{87}Sr/^{86}Sr$ was analyzed for all large geological formations found within a 2,640 km^2 section of the Peruvian north-central highlands surrounding the study sites (Figure 6.2; Washburn et al. in review).

6.4.3 Statistical Data Analyses

Three linear mixed models were run in R (version 3.6.3., R core team, 2013), each testing for the effects of site, sex and burial type on the responses $\delta^{13}C$, $\delta^{15}N$ (n =101) and $^{86}Sr/^{87}Sr$ (n=53) and including the random effect of tooth type to control for isotopic differences between teeth forming at different ages (Supplementary information S6.1).

Relative contributions of potential dietary sources were determined using the SIAR v4 (Stable Isotope Analysis in R, Parnell et al., 2010). SIAR provides a mixing model for estimating proportional contributions of different possible food sources in a consumer's diet (Parnell et al. 2010; Koch and Phillips 2002; Phillips and Koch 2002; Washburn et al. 2020, see Supplementary information S6.1 for details).

6.5 Results

6.5.1 δ^{13}C and δ^{15}N Isotope Data

All samples have atomic C/N ratios that range between 2.9 and 3.6, suggesting tooth collagen was well preserved (Ambrose and Norr 1993; DeNiro and Hastorf 1985). The δ^{13}C values of human collagen from all sites range from -17.0‰ to -12.4‰ with an average value of -14.2‰, whereas the δ^{15}N values range from 7.7‰ to 11.5‰ with an average value of 9.4‰ (Table 6.1; Figure 6.3; Table S6.4). Based on these values, the diets of individuals from Marcajirca, Jato Viejo and Ushcugaga represent a predominantly C_4 plant diet supplemented by high trophic level terrestrial protein (such as camelids and/or guinea pig).

Table 6.1: Descriptive statistics for δ^{13}C and δ^{15}N and ^{87}Sr/^{86}Sr from Marcajirca, Ushcugaga and Jato Viejo

	Marcajirca	**Ushcugaga**	**Jato Viejo**
δ^{13}C			
Mean	**-14.2**	**-13.6**	**-15.7**
Std dev.	0.81	0.95	1.22
Range (‰)	-16.6 to -13.0	-16.3 to -12.4	-17.0 to -12.8
δ^{15}N			
Mean	**9.3**	**9.8**	**9.4**
Std dev.	0.62	0.87	0.92
Range (‰)	7.9 to 10.9	7.7 to 11.5	8.9 to 11.2
^{87}Sr/^{86}Sr			
Mean	**0.7115**	**0.7104**	**0.7101**
Std. dev.	0.0007	0.0011	0.0004
Human Range	0.7100 to 0.7125	0.7095 to 0.7125	0.7096 to 0.7106
Bioavailable Range	**0.7107-0.7116**	**0.7111-0.7133**	**0.7092-0.7111**

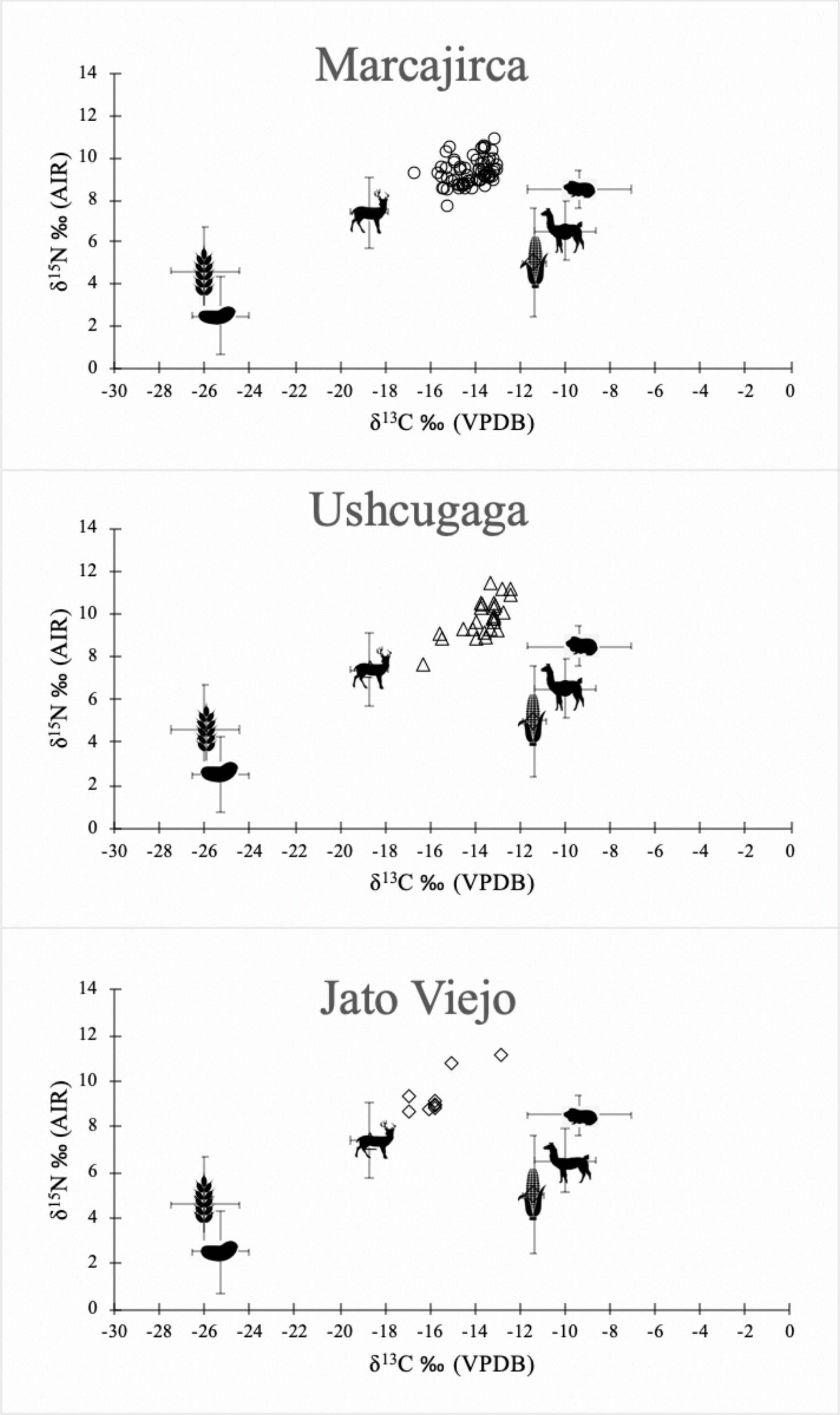

Figure 6.3: Human $\delta^{13}C$ and $\delta^{15}N$ data (n=101) for the sites (A) Marcajirca, (B) Ushcugaga, and (C) Jato Viejo. See Table S6.2 for dietary source data.

The full $\delta^{13}C$ model was significant ($\chi^2 = 36.3$, df = 5, $p < 0.0001$), driven by the effect of site ($p < 0.0001$), and the effect of sex ($p = 0.0394$), whereas burial type had no effect. Marcajirca had on average 1.5‰ higher, and Ushcugaga had on average 2‰ higher $\delta^{13}C$ values than the site of Jato Viejo. At all three sites, males had on average 0.2‰ higher $\delta^{13}C$ values than females (Figure S6.4a). Based on a dietary mixing model, males consumed on average 4% more C_4 plants in their diet (3% at Marcajirca, 5% at Jato Viejo and 4% at Ushcugaga) compared to females at each respective site. This would seem to indicate that males and females were consuming maize in relatively equal amounts, which was the case elsewhere in highland Peru during this time (Hastorf, 1991).

The full $\delta^{15}N$ model was significant ($\chi^2 = 4.0$, df = 5, $p = 0.0155$), but here only the predictor site had an effect ($p = 0.0077$), not sex or burial type. Marcajirca individuals had on average 0.2‰ lower values than individuals at the site of Jato Viejo, whereas individuals from Ushcugaga had on average 0.4‰ higher $\delta^{15}N$ values than individuals from Jato Viejo (Figure S6.4b). However, compared to the dietary differences reflected by $\delta^{13}C$ values, these differences in $\delta^{15}N$ are negligible and close to the analytical error.

Finally, the full-null comparison for the $^{86}Sr/^{87}Sr$ model was also significant ($\chi^2 = 19.4$ df = 5, $p = 0.0016$), but again only the predictor site had a significant effect ($p = 0.0175$), whereas sex and burial type did not. Individuals from the site of Marcajirca have on average 0.00125 higher values than individuals from the two other sites (Figure S6.5).

6.5.2 Dietary Mixing Models

To assess the proportions of food resources (i.e. C_4, C_3, legumenous plants, foddered camelids, grazers, and guinea pigs) (group 1 and group 2) within the diet of individuals from each archaeological site, we ran a dietary mixing model. Each individual $\delta^{13}C$ and $\delta^{15}N$ value was input into the model and sorted by the archaeological site in which the remains were found. Remains found at Marcajirca were further separated by burial context. The dietary mixing model averages these input values for each archaeological site and estimates the probability of the percentage (i.e. 25, 75, and 95%) of diet for each dietary resource.

Model simulations suggest that the majority of indivdiuals from all three archaeologicals sites have diets consisting primarily of C_4 plants, presumably maize. We estimate that maize constituted between 25-60% (75% credibility interval) of the modeled diet (Figure S6.6), supplemented by terrestrial meat protein sources (Figure S6).

At all three sites there is little to no consumption of C_4 foddered camelids (Figure S6.4), but there is a high proportion of (between 0-40% [75% credibility interval] of the modeled diet) of animals that grazed on C_3 plants (Figure S6.6). This finding strongly suggests reliance on the high altitude *puna* grasslands. However, it should be noted that the "grazer group" input for the model consists of $\delta^{13}C$ and $\delta^{15}N$ values of both wild white-tailed deer (*Odocoileus virginianus*) (Washburn et al., 2020), as well as domesticated camelids that grazed on C_3 grasses (Finucane et al.

2006). The mixing model cannot differentiate between grazers because these species have $\delta^{13}C$ and $\delta^{15}N$ values that overlap.

The results of our model also suggest consumption of guinea pig (*Cavia porcellus*) as an additional source of dietary protein (Figure S6.6). As dependent scavengers, guinea pigs have diets that represent the food provided over the lifetime of the animal (Finucane et al., 2006). The importance of guinea pig may be explained by the high $\delta^{15}N$ values observed in both groups of guinea pig (group 1: mean 8.3‰ and group 2: mean 8.5‰).

6.5.3 $^{87}Sr/^{86}Sr$ Isotope Data

$^{87}Sr/^{86}Sr$ was measured in a representative sample of human dental enamel (n=53) in order to examine patterns of residential mobility. The repeated $^{87}Sr/^{86}Sr$ measurement of the SRM 987 standard resulted in an average value of 0.7094 ±0.00011. The procedural blanks (1 out of every 9 samples), were considered negligible, suggesting no sample cross contamination. Human $^{87}Sr/^{86}Sr$ values from: a) Marcajirca range from 0.7100 to 0.7125; b) Ushcugaga range from 0.7095 to 0.7125; and c) Jato Viejo range from 0.7096 to 0.7106.

Regional environmental Sr data (Washburm et al. in review) was used to reconstruct the local bioavailable $^{87}Sr/^{86}Sr$ range for each archaeological site (Marcajirca = 0.7107-0.7116; Jato Viejo = 0.7092-0.7111; and Ushcugaga = 0.7111-0.7133) (Figure 6.4). Based on these bioavailable $^{87}Sr/^{86}Sr$ ranges, 42% of all individuals measured at Marcajirca can be considered geologically non-local to the site, but are probably local to the Conchucos region (Figure 6.4a). Most of the geologically non-local individuals found at Marcajirca are from Structure 10, where 90% have $^{87}Sr/^{86}Sr$ values that fall outside the established local range (Figure 6.4a). Within Structure 10 there are two distinct groups with geologically non-local $^{87}Sr/^{86}Sr$ values (Group 1 = 0.7098-0.7104 and Group 2 = 0.7120-0.7125), suggesting that this tomb was used by groups coming from two separate regions, presumably east of Marcajirca (Figure 6.2).

At Ushcugaga, 80% of individuals have $^{87}Sr/^{86}Sr$ values that fall outside the established bioavailable local range (0.7111-0.7133) (Figure 6.4b). In contrast, all individuals found at Jato Viejo can be characterized as local to the region where the site is located, where individuals have $^{87}Sr/^{86}Sr$ values within the local bioavailable range (0.7092-0.7111) (Figure 6.4c).

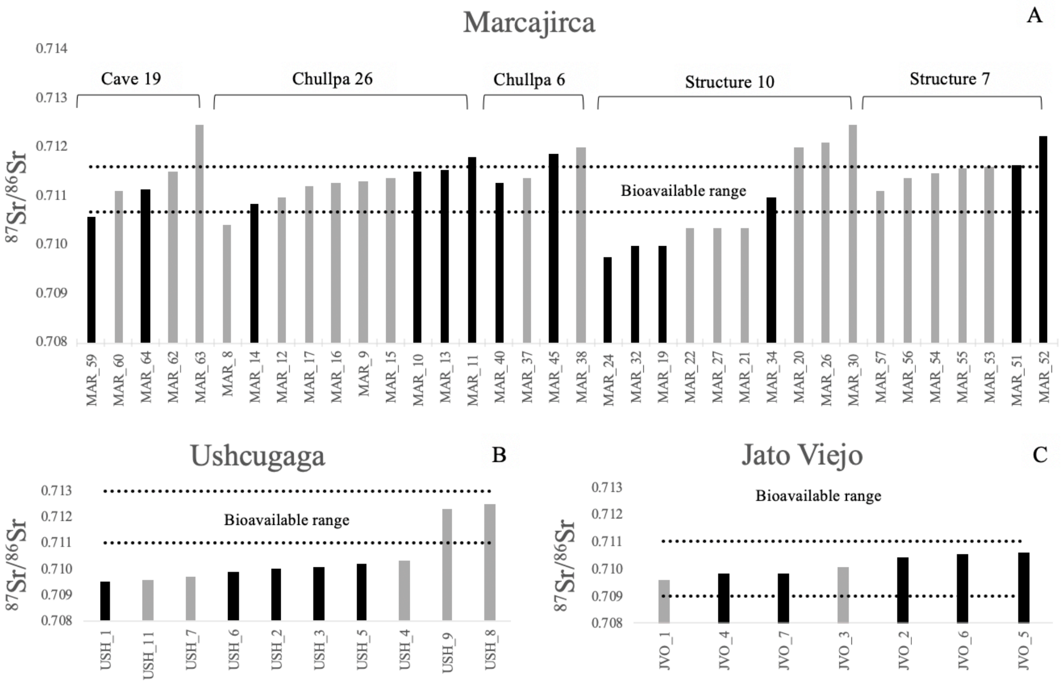

Figure 6.4: $^{87}Sr/^{86}Sr$ values of human tooth enamel from (A) Marcajirca, (B) Ushcugaga and (C) Jato Viejo. Males indicated by grey bars, while females are represented by black bars. Dashed lines represent the upper and lower limits of the calculated bioavailable $^{87}Sr/^{86}Sr$ range for each site.

6.6 Discussion

6.6.1 Diet During the LIP

Isotopic data suggests that the individuals buried at Marcajirca, Ushcugaga, and Jato Viejo relied primarily on maize, low quantities of C_3 plants, camelids and guinea pig. We assert that this diet reflects a subsistence economy that included ecological complementarity between different production zones. Mean $\delta^{13}C$ values are -14.2‰ for Marcajirca, -13.6‰ for Ushcugaga, and -15.7‰ for Jato Viejo, suggesting considerable contribution of C_4 resources. Based on the dietary mixing models, C_4 plants (i.e. maize) played a significant role in the diet of individuals at all three sites (75% confidence interval: 25-60% of the modeled diet). In this part of Peru, the upper limits of effective maize cultivation is approximately 3,400 masl. Because the sites discussed in this paper are all situated above 3,500 masl, the regular consumption of maize in these populations suggests: a) people moved regularly down mountain slopes in order to access lower elevation zones, and/or b) they established exchange relationships with these areas to acquire maize.

From a broader perspective, the observed pattern of maize consumption during the LIP in the Conchucos region is similar to other parts of highland Peru (e.g. Hastorf 1990, 1991; Hastorf and Johannessen 1993; Lofaro et al. 2019). The results from this study most closely resemble isotopic patterns from contemporary burials from the Mantaro region of central Peru. Burials from the Wanka II period (AD 1350-1460) showed a mean $\delta^{13}C$ value of -17.63‰, while Wanka III (AD 1460-1533) burials have a mean $\delta^{13}C$ value of -14.93‰ (Hastorf 1990; Hastorf and Johnannessen

1993). Data from mixing models indicate that on average, males consumed c. 4% more maize than females (Figure S6.4a). In our view this difference is negligible and suggests that during the LIP, access to maize and other foods was not associated with gendered inequity (see Hastorf 1991). Instead, access to maize was seemingly equal, a pattern that changes in some parts of Peru during Inca times (c.f. Hastorf 1991; Burger et al. 2003).

Our data indicate that while important, maize was not the only crop consumed during the LIP in the Conchucos region. The results of our dietary mixing model identify a small proportion of C_3 plants in the modeled diet (0-10%, 75% credibility interval). This low proportion of C_3 plants in the diets of individuals at all three archaeological sites is surprising as C_3 plants comprise many domesticated crops found in the central highlands, including quinoa, potatoes, and other tubers (Hastorf, 1990; Hastorf and Johannessen, 1993). While C_3 plants were not a significant proportion of diet, grazers who fed primarily on C_3 plants do represent a high proportion (up to 60%, 75% credibility interval).

$\delta^{15}N$ values suggest diet also comprised terrestrial animal protein, consistent with the consumption of terrestrial grazers like camelids and guinea pig. Though it is isotopiclly difficult to distinguish between deer and camelids, some evidence suggests that the LIP inhabitants of Conchucos were relying on domesticated camelids. Zooarchaeological data show that after 800/750 BC, camelid herding largely replaced the hunting of deer in the Conchucos region (Miller and Burger 1995; Rosenfeld and Sayre 2016), a pattern that continued into later times in the north-central highlands

(Lau 2007). Our data suggest that camelids were eating C_3 plants rather than maize fodder, indicating that they were likely herded/pastured in the high-elevation *puna* grasslands. Our $\delta^{15}N$ data also point to guinea pig as an additional dietary resource. Ethnographic and archaeological research describe guinea pigs as a feast food that was typically only consumed during certain parts of the year (Bolton 1979; Gade 1967).

The variation in $\delta^{13}C$ and $\delta^{15}N$ values at Marcajirca, Ushcugaga and Jato Viejo represent differences in site location as well as the different available ecological resources. However, the presence of C_4 plants, as well as protein sources such as camelids indicate a significant reliance on ecological zones not immediately accessible from each site. $\delta^{13}C$ and $\delta^{15}N$ data from our study suggests that during the LIP, groups living within the Conchucos region practiced a form of ecological complementarity (Murra 1972, 1985), where groups either established access to a wide range of resources through physical access to lands, and/or exchange networks.

6.6.2 Mobility during the LIP

Human $^{87}Sr/^{86}Sr$ values were compared to a regional isoscape (Washburn et al. in review), to determine if similar $^{87}Sr/^{86}Sr$ values are found within the broader Conchucos region. The Conchucos region is geologically complex and is shaped by folded and uplifted layers of bedrock, with differing geologic ages and $^{87}Sr/^{86}Sr$ values. Within relatively short distances between environmental sampling locations there are considerable differences in mean $^{87}Sr/^{86}Sr$ values per geological unit that range from as low as 0.7081 to as high as 0.7212 within just 10-20 km distance (Figure 6.2). This means that the entire variation in human values observed (n=53; 0.7096-0.7125) can have geologic origins within the Conchucos region, suggesting mobility during the LIP was probably restricted to within this valley system. Our $^{87}Sr/^{86}Sr$ data support the assumtion of trade networks and/or local human mobility during the LIP, as discussed above.

In the case of Marcajirca, roughly 58% (n=21) of the burials have $^{87}Sr/^{86}Sr$ values indicating that the individuals were local to the region in which the settlement was located (Figure 6.4). This is particularly the case for the chullpas and caves. Individuals interred within these contexts were all from the local region and lends support to the notion that chullpas and caves corresponded to extended kin groups. The remainder (n=16) exhibit $^{87}Sr/^{86}Sr$ ranges that can be classified as non-local (Figure 6.4), and indicate that they came to the site at some point during their adult life or were brought to Marcajirca for burial.

Most non-local individuals come from Structures 7 and 10, which are two atypical below-ground burials found at Marcajirca, both of which contain a large number of individuals. The majority of individuals buried (n=6 local; n=1 non-local) in Structure 7 have $^{87}Sr/^{86}Sr$ values falling within the bioavailable range of Marcajirca and would therefore be considered local. Structure 10 on the other hand, contains only one female individual with a local $^{87}Sr/^{86}Sr$ value, while the majority of individuals (n=9) have $^{87}Sr/^{86}Sr$ values that could be considered non-local. Questions remain about the function of these two below-ground burials as well as the connection between the individuals found in Structure 10 and the rest of the population at Marcajirca. Additional research methodologies, such as paleogenomics and oesteological analyses, are underway to address these questions.

In contrast to Marcajirca, Jato Viejo and Ushcugaga are exclusively cave burial cemeteries. At Ushcugaga, the majority of individuals have non-local $^{87}Sr/^{86}Sr$ values that suggests these individuals were brought to the site for burial. The consisteny of $^{87}Sr/^{86}Sr$ values within both sites also suggest that these individuals originated from the same geologic region (Figure S6.5). Based on $^{87}Sr/^{86}Sr$ values from environmental reference samples from within the immediate vicinity of Jato Viejo (Washburn et al, in review), all individuals sampled could be considered to have resided in proximity of the burial site.

In the Central Andes, the LIP is traditionally defined as a time of political instability and fragmentation, with groups moving their settlements to higher altitudes for defensive purposes (Álvarez and Greco 2018; Arkush 2008, 2011; Arkush and Stanish 2005; Arkush and Tung 2013; Bauer and Kellett 2010; Bauer et al. 2010; Ibarra 2020; Jolly and Kurin 2017; Kellett 2010; Lofaro et al. 2018; Kurin 2013; Meddens and Branch 2010; Torres-Rouff et al. 2005; Tung 2008; Tung et al. 2016). This presents a model of groups of people living in isolation from one another, with little interaction for security and protection. In this study, we present an alternative picture of life in the Andean highlands where people even under potential duress continued to interact with each other, moved around the landscape, and/or created trade networks without which subsistence would have been much more challenging.

Acknowledgements

We would like to thank Terry Blackburn, Brian Dreyer, W.M. Keck Laboratory Staff, and Colin Carney for their continued support with isotope analysis. In addition, we also thank Jelmer Eerkens and Judith Habicht Mauche for their invaluable mentorship throughout this project. We thank Rachel Johnson and Alana Garvey for their contributions to sample collection in the field. The permission for sampling and research was obtained under Resolución Directoral Nacional numbers: RD 161-2018, RD 178-2017 and RD 198-2016. Import Permits for all plants and snail shells utilized in this project were granted by the United States Department of Agriculture; Animal and Plant Health Inspection Service (Permit Number: PCIP-18-00364). This research was funded by the National Science Foundation (NSF - 1842447).

Supplementary Information

S6.1: Methods

Minimum number of individuals

The minimum number of individuals (MNI) was calculated based on the duplication of skeletal elements within this assemblage. MNI is useful in this context where all remains were commingled. When possible, elements were sorted by body side, age, sex and size to estimate the greatest MNI present (Table S6.1).

Radiocarbon dating

In the present study, we directly radiocarbon dated at least one individual from six tombs at Marcajirca (2 chullpas, 2 caves, 2 underground burials), and at least one individual (each) from Jato Viejo and Ushcugaga were also directly radiocarbon dated. Ten bone/dentine samples were sent to the UC Irvine W. M. Keck Carbon Cycle Accelerator Mass Spectrometry Laboratory (n=8) and the Pennsylvania State University Human Paleoecology and Isotope Geochemistry Laboratory (n=2). Radiocarbon dates were calibrated with the mixed calibration curve on OxCal v. 4.3.2, which is the most applicable curve for this part of Peru (Marsh et al. 2018; see Nesbitt et al. 2020 for an application in the study region). This calibration curve accounts for the potential variation between IntCal and SHCal.

Morphological sex estimation

Due to the extensive commingling of skeletal remains from Marcajirca, Jato Viejo and Ushcugaga, morphological estimations of sex were determined using the skulls (Buikstra and Ubelaker, 1994) from which teeth were extracted for genetic and isotopic analysis. Examined features include the robusticity of muscle attachments on the cranial vault (i.e. nuchal area and the mastoid process), forehead shape, supraorbital tori, and chin shape (when applicable).

Paleogenomic sex determination

A subset of samples reported in this study (n=38) were also subject to paleogenomic analysis; we only report the results for chromosomal sex here (Table S4). Tooth samples were processed at the clean room facilities of the University of California Paleogenomics Lab (UC-PGL) following established procedures to prevent contamination (Llamas et al. 2017; Fehren-Schmitz et al. 2017). Each sample was photographed before destructive analysis. Laboratory tools used were either sterile or decontaminated with full strength household bleach (6%) or Alconox (Alconox, Inc.) and exposed to UV light before use.

Approximately 100 milligram of bone or tooth root was cut from each sample. Extractions were performed using an established protocol especially sufficient for highly fragmented DNA (Dabney et al. 2013), adding an additional 15-minute pre-digestion step during the lyses protocol in which bone powder is mixed with 0.5%

bleach solution as suggested by Boessenkool et al. (2016). This approach has been shown to remove contaminating DNA present on the bone before lysis begins. Each extraction batch was accompanied by at least one extraction blank.

Partially UDG-treated single stranded DNA libraries were constructed following the protocol by Troll et al. (2019) for all samples. The success of the library construction, quantity, and length was evaluated using the TapeStation 2200 (Agilent) and Qubit (Invitrogen). Each library was sequenced on an Illumina NextSeq 500 sequencer at for ~600,000 reads using the 2x75 paired end mode to evaluate library quality. Base-calling was performed using the Illumina software CASAVA 1.8.2. Raw reads were assigned to the corresponding samples based on the index sequence included in the adapter P7 and P5, allowing no mismatches. Using an in-house script (https: //github.com/mjobin/batpipe), adapters were trimmed, reads merged, and mapped to the human reference genome using the software Burrows-Wheeler Aligner (BWA) version 0.7.5a-r405 7, with default parameters and seed option disabled (-l 1000). All raw sequence data processing steps and parameters were followed as described in Fehren-Schmitz et al. (2017). We used hg19 (GRCh37 build) as reference genome, excluding the mitochondrial contigs. Mitochondrial reads were mapped to the revised Cambridge Reference Sequence (rCRS, NC_012920; 8) employing the same BWA parameters.

We estimated patterns of DNA damage using MapDamage 2 (Jonsson et al., 2013) and observed that damage for all samples ranged between 3-20% at the terminal bases as to be expected for ancient DNA samples (Rohland et al., 2014). We further estimated mitochondrial contamination rates employing the modules contDeam and mtCont implemented in the software tool SCHMUZTI using the recommended parameters (Renaud et al., 2015). However, the number of mitochondrial reads obtained in the screening were not sufficient to obtain an estimate. To overcome the potential risk of contamination we used PMDtools (Skoglund et al, 2014) to exclude all reads without ancient DNA characteristic damage as expressed in terminal cytosine-to-thymine substitution rates, leaving only DNA reads that exhibit sufficient damage for the subsequent genetic sex determinations and other downstream analyses.

We applied two different approaches to determine chromosomal sex from sequencing read data of ancient DNA samples. Following Skoglund et al. (2013), sex for all samples was determined by evaluating the ratio (Ry) of reads aligning to the Y chromosome (nY) compared to the total number of reads aligning to the sex chromosomes (nX + nY), i.e., Ry = (nY/nY+nX). We also employed the X-chromosomal normalization rate (Rx) approach introduced by Mittnik et al. (2016). This compares Rx to the variability observed in all 22 autosomes, promising higher accuracy for sex determination. Finally, biological sex for each individual was only assigned if both methods delivered results, and if the results of both methods were consistent (Table S6.5). If these two criteria were not satisfied, we note the sex of the individual as not determined (n.d.) determination for each individual was done as a consensus of both methods.

Statistical Data Analyses

We conducted statistical analysis in R (version 3.6.3., R core team, 2013). We ran linear mixed models (LMMs) with Gaussian error structure which were fit by maximum likelihood using the function lmer (package lme4) and the significance level set to 0.05. In the first two models with a focus on light stable isotopes and diet we tested the main effects of site (Jato Viejo, Marcajirca, Ushcugaga), sex (male, female) and burial type (cave, chullpa or underground burial) each on one of the two response variables $\delta^{13}C$ and $\delta^{15}N$ values measured in 101 samples of human dentin collagen. In both of these models, we included a random effect of tooth type (M1, M2 or M3) to control for potential variation between molars forming at different ages, given that not the same tooth could be sampled for each individual. In the third model, we ran the same model as above but on the response $^{86}Sr/^{87}Sr$ values measured in a total of 53 human enamel samples.

For all three models, we conducted model diagnostics by visually inspecting histograms, qq-plots and the residuals plotted against fitted values; all confirmed normally distributed and homogeneous residuals. We tested variance inflation factors from the results of standard linear models excluding the random effect of tooth type and found no evidence for collinearity. Finally, model results were obtained by testing the full models compared to null models excluding the main effects using chi-square tests of independence.

Dietary Mixing Models

To assess the proportions of food resources (i.e. C_4, C_3, legumenous plants, foddered camelids, grazers, and guinea pigs (group 1 and group 2) within the diet of indivivuals from each archaeological site, we ran a dietary mixing model. Each dietary source was condensed into an average δ13C and δ15N value (± 1σ) and used as the source dietary input for the models (Table S6.2). This model has a limit of 30 consumer groups (i.e. grouped human δ13C and δ15N values) and between 3-7 observations (i.e. dietary source groups; n=7; C_4, C_3, leguminous plants, foddered camelids, grazers, and guinea pigs (group 1 and group 2). Despite these limitations, mixing models allow us to estimate, quantify and discuss the relative contribution of certain food categories to past human diets, which is of considerable value to the archeological interpretation of past lifeways.

S6.2: Results

Radiocarbon Dates

Radiocarbon measurements at all three sites yielded calibrated age ranges of the 14th-15th centuries AD (95.4% confidence interval), and therefore fall into the later part of the LIP (Table S6.3; Figure S6.3). As illustrated in Figure S6.3, these dates overlap suggesting that the three sites may have been partially contemporary.

Supplementary Tables

Table S6.1: Estimated minimum number of invividuals (MNI) and sample size for each burial context

Archaeological Site	Burial Context	MNI	Sample size: $\delta^{13}C$ and $\delta^{15}N$	Sample size: $^{87}Sr/^{86}Sr$
Marcajirca	Cave 19	30	5	5
	Cave 21a	20	17	--
	Chullpa 26	28	10	10
	Chullpa 6	33	6	4
	Structure 10	34	21	10
	Structure 7	12	7	7
			N= 66	**N= 36**
Ushcugaga	Cave 2	Unknown	5	5
	Cave 4	Unknown	2	--
	Cave 5	Unknown	5	5
	Cave 7	Unknown	2	--
	Cave 8	Unknown	1	--
	Cave 10	Unknown	1	--
	Cave 13	Unknown	3	--
	Cave 14	Unknown	2	--
	Cave 15	Unknown	1	--
	Cave 16	Unknown	3	--
			N= 25	**N= 10**
Jato Viejo	Cave 1	10	9	7
			N= 9	**N= 7**

Table S6.2: Average $\delta^{13}C$ and $\delta^{15}N$ values for dietary sources used in the SIAR mixing models (data compiled from DeNiro and Hastorf, 1985; Finucane et al., 2006; Turner et al., 2010 and Washburn et al., 2020)

Source	N	Mean $\delta^{13}C$ ‰	1σ	Mean $\delta^{15}N$ ‰	1σ
C_3	45	-26.0	1.5	4.6	2.1
C_4	13	-11.4	0.5	5.0	2.6
Legumes	41	-25.3	1.3	2.5	1.8
C_4 Foddered Camelids	11	-10.0	1.4	6.5	1.4
C_3 Grazers	10	-18.7	0.8	7.4	1.7
Guinea Pig – Group 1	8	-17.1	1.3	8.3	0.4
Guinea Pig – Group 2	10	-9.4	2.3	8.5	0.9

Table S6.3: Radiocarbon dates for Marcajirca, Ushcugaga, and Jato Viejo. Dates were calibrated using the mixed calibration curve (Marsh et al. 2018) using OxCal v. 4.3.2.

Lab No.	Sample Name	Sample Material	^{14}C age (BP)	Burial	1-sigma (AD)	2-sigma (AD)
UCIAMS-185294	MAR_18	Human bone	485±15	Chullpa 26	1432-1446	1442-1452
UCIAMS-185295	MAR_25	Human bone	565±15	Structure 10	1398-1419	1324(12.3%)1344 1392(83.1%)1429
PSU-4540	MAR_33	Human bone	490±15	Structure 10	1430-1445	1420-1451
UCIAMS-185296	MAR_49	Human bone	430±15	Chullpa 6	1446-1473	1440-1496
PSU-4541	MAR_50	Human bone	595±15	Chullpa 13	1324(34.8%)1344 1392(33.4%)1406	1314(52.9%)1356 1386(42.5%)1413
UCIAMS-185297	MAR_58	Human bone	485±15	Structure 7	1432-1446	1422-1452
UCIAMS-185298	MAR_65	Human bone	480±15	Cave 19	1432-1448	1424-1454
UCIAMS-213823	USH_7	Human tooth	625±15	Cave 5	1316(53.7%)1355 1386(14.5%)1396	1301(73.3%)1367 1380(22.1%)1400
UCIAMS-213824	USH_21	Human tooth	575±20	Cave 21	1330(10.7%)1338 1394(57.5%)1416	1320(28.8%)1350 1389(66.6%)1425
UCIAMS-213830	JVO_9	Human tooth	560±20	Cave 1	1398-1423	1323(12.1%)1346 1391(83.3%)1434

Table S6.4: Archaeological context information and results of δ^{13}C, δ^{15}N (collagen) and ^{87}Sr/^{86}Sr (enamel) analysis. For the 101 adult human invididuals in this study all sex estimations are based on morphological observations (M = male; F= female; (M)= probabale male; (F)= probable female) and were partly confirmed by paleogenomic anlayses (*sex confirmed/determined using aDNA; **aDNA falsified morphological assesment).

Site	Tomb	Sample ID	Sex	Molar	δ^{13}C ‰	%C	δ^{15}N ‰	%N	C/N (%)	C/N	^{87}Sr/^{86}Sr	S.E. (%
Marcajirca	Cave 19	MAR_59	F	M^2	-14.68	45.2	8.50	16.0	2.8	3.3	0.7106	0.001
Marcajirca	Cave 19	MAR_60	M	M^2	-13.38	44.2	8.98	15.9	2.8	3.3	0.7111	0.001
Marcajirca	Cave 19	MAR_62	(M)	M^2	-14.35	44.3	9.15	15.7	2.8	3.3	0.7115	0.001
Marcajirca	Cave 19	MAR_63	M	M^1	-15.24	44.5	9.50	16.1	2.8	3.4	0.7125	0.0009
Marcajirca	Cave 19	MAR_64	F*	M^2	-15.65	43.2	9.27	15.5	2.8	3.3	0.7112	0.001
Marcajirca	Cave 21a	MAR_69	M*	M_1	-13.69	44.0	9.74	16.2	2.7	3.3		
Marcajirca	Cave 21a	MAR_70	M	M_2	-13.19	41.6	9.28	15.4	2.7	3.2		
Marcajirca	Cave 21a	MAR_71.1	F	M_3	-13.05	43.1	9.36	15.6	2.8	3.3		
Marcajirca	Cave 21a	MAR_72	(F)	M_1	-14.91	38.4	8.90	13.9	2.8	3.2		
Marcajirca	Cave 21a	MAR_73	F	M_2	-14.42	40.7	8.55	15.3	2.7	3.2		
Marcajirca	Cave 21a	MAR_74	F	M_1	-13.02	43.7	9.60	15.9	2.7	3.3		
Marcajirca	Cave 21a	MAR_75	M	M_2	-13.27	44.5	10.29	15.8	2.8	3.3		
Marcajirca	Cave 21a	MAR_76	F	M_1	-14.54	42.6	8.59	15.8	2.7	3.3		
Marcajirca	Cave 21a	MAR_77	(M)	M_1	-14.49	39.8	8.77	14.8	2.7	3.3		
Marcajirca	Cave 21a	MAR_78	M	M_1	-14.71	40.2	8.72	14.7	2.7	3.3		
Marcajirca	Cave 21a	MAR_79	M	M^2	-14.48	45.0	8.71	16.1	2.8	3.3		
Marcajirca	Cave 21a	MAR_80	F	M^1	-13.57	44.4	9.79	16.0	2.8	3.3		
Marcajirca	Cave 21a	MAR_81	(F)	M^2	-13.34	44.9	9.92	15.6	2.9	3.3		
Marcajirca	Cave 21a	MAR_82	F	M^3	-13.58	46.0	10.54	16.0	2.9	3.4		
Marcajirca	Cave 21a	MAR_83	M	M^1	-15.18	44.0	7.68	16.2	2.7	3.3		
Marcajirca	Cave 21a	MAR_84	(M)*	M^1	-13.32	44.3	9.09	16.4	2.7	3.2		
Marcajirca	Cave 21a	MAR_85	M	M^2	-13.20	41.2	8.92	14.7	2.8	3.3		
Marcajirca	Chullpa 26	MAR_8	M*	M_2	-13.41	43.3	9.78	15.4	2.8	3.3	0.7104	0.001
Marcajirca	Chullpa 26	MAR_9	(M)*	M_3	-13.14	41.3	9.98	15.4	2.7	3.3	0.7113	0.0018

Marcajirca	Chullpa 26	MAR_10	F	M_3	-15.46	42.5	9.06	14.6	2.9	3.4	0.7115	0.0023
Marcajirca	Chullpa 26	MAR_11	F*	M_3	-13.85	43.8	9.40	15.2	2.9	3.4	0.7118	0.0014
Marcajirca	Chullpa 26	MAR_12	M	M_1	-13.08	43.9	10.91	16.0	2.7	3.3	0.711	0.001
Marcajirca	Chullpa 26	MAR_13	PF	M_2	-13.50	41.7	9.13	14.8	2.8	3.3	0.7116	0.0009
Marcajirca	Chullpa 26	MAR_14	PF	M_3	-14.10	43.0	8.95	15.2	2.8	3.3	0.7109	0.001
Marcajirca	Chullpa 26	MAR_15	M	M_3	-15.09	45.6	10.51	16.0	2.9	3.3	0.7114	0.0006
Marcajirca	Chullpa 26	MAR_16	M	M_2	-14.06	43.5	10.08	15.3	2.8	3.3	0.7113	0.0011
Marcajirca	Chullpa 26	MAR_17	M	M_1	-14.59	43.9	9.39	16.2	2.7	3.3	0.7112	0.0014
Marcajirca	Chullpa 6	MAR_37	M*	M_3	-14.35	43.5	8.78	15.8	2.8	3.3	0.7114	0.0006
Marcajirca	Chullpa 6	MAR_38	M*	M_3	-14.98	43.4	8.82	15.9	2.7	3.2	0.712	0.0018
Marcajirca	Chullpa 6	MAR_40	F*	M_1	-15.18	41.1	9.00	14.8	2.8	3.3	0.7113	0.0007
Marcajirca	Chullpa 6	MAR_45	F*	M_2	-14.55	44.8	8.72	15.9	2.8	3.3	0.7119	0.0006
Marcajirca	Chullpa 6	MAR_47	M	M_1	-14.40	41.9	9.49	15.3	2.7	3.3		
Marcajirca	Chullpa 6	MAR_48	(M)	M_3	-13.49	42.7	9.27	15.4	2.8	3.3		
Marcajirca	Structure 10	MAR_19	F*	M^2	-15.50	37.4	9.59	11.6	3.2	3.4	0.710	0.0006
Marcajirca	Structure 10	MAR_20	M	M_3	-13.81	43.3	9.40	14.8	2.9	3.4	0.7120	0.001
Marcajirca	Structure 10	MAR_21	M*	M^2	-14.60	35.9	9.54	12.4	2.9	3.4	0.7104	0.0011
Marcajirca	Structure 10	MAR_22.1	M*	M^2	-13.68	41.6	9.29	14.5	2.9	3.4	0.7104	0.0014
Marcajirca	Structure 10	MAR_23	M*	M^1	-14.94	43.7	9.84	15.8	2.8	3.3		
Marcajirca	Structure 10	MAR_24	F*	M^1	-15.31	43.5	10.28	15.7	2.8	3.3	0.7098	0.0019
Marcajirca	Structure 10	MAR_26	M	M^1	-13.56	43.1	8.61	14.9	2.9	3.3	0.7121	0.0018
Marcajirca	Structure 10	MAR_27	M*	M_2	-13.54	37.0	9.07	12.8	2.9	3.4	0.7104	0.0013
Marcajirca	Structure 10	MAR_28	M	M^1	-14.75	42.2	8.68	15.1	2.8	3.2	0.710	0.002
Marcajirca	Structure 10	MAR_30	(M)	M_2	-15.35	43.6	8.57	14.9	2.9	3.4	0.7125	0.002
Marcajirca	Structure 10	MAR_34	F	M^2	-16.66	43.3	9.22	13.1	3.3	3.3	0.7110	0.002
Marcajirca	Structure 10	MAR_86	F	M_1	-13.74	37.9	8.96	13.8	2.7	3.3		
Marcajirca	Structure 10	MAR_87	F	M_1	-13.79	40.6	8.90	14.4	2.8	3.3		
Marcajirca	Structure 10	MAR_88	(M)	M_2	-13.70	36.7	10.43	13.1	2.8	3.3		
Marcajirca	Structure 10	MAR_89	(F)	M_1	-13.60	41.4	9.18	14.9	2.8	3.3		
Marcajirca	Structure 10	MAR_90	M	M	-13.63	44.0	10.38	15.5	2.8	3.4		
Marcajirca	Structure 10	MAR_91	F	M_1	-14.95	42.6	9.75	15.7	2.7	3.3		
Marcajirca	Structure 10	MAR_92	F	M_1	-14.27	40.6	8.84	14.5	2.8	3.3		

Marcajirca	Structure 10	MAR_93	F	M^1	-13.75	41.4	8.96	14.92.8	3.2		
Marcajirca	Structure 10	MAR_94	M	M_2	-13.54	43.7	10.46	15.42.8	3.3		
Marcajirca	Structure 10	MAR_95	F	M^2	-13.73	40.8	8.95	14.82.8	3.3		
Marcajirca	Structure 7	MAR_51	F*	M^1	-14.11	43.0	8.51	15.32.8	3.4	0.7117	0.0009
Marcajirca	Structure 7	MAR_52	(F)*	M^2	-15.42	44.4	8.52	15.32.9	3.3	0.7123	0.0008
Marcajirca	Structure 7	MAR_53	M*	M^2	-13.87	40.3	8.90	14.42.8	3.3	0.7116	0.001
Marcajirca	Structure 7	MAR_54.1	M*	M^2	-13.34	43.3	9.13	15.32.8	3.3	0.7115	0.001
Marcajirca	Structure 7	MAR_55	M*	M^2	-14.63	39.5	9.43	13.72.9	3.4	0.7116	0.001
Marcajirca	Structure 7	MAR_56	M*	M^2	-13.87	42.3	9.84	15.12.8	3.3	0.7114	0.001
Marcajirca	Structure 7	MAR_57	M*	M^2	-15.21	40.4	8.50	13.92.9	3.4	0.7111	0.001
Jato Viejo	Cave 1	JVO_1	F**	M^2	-15.81	43.4	8.80	15.82.7	3.2	0.7096	0.0008
Jato Viejo	Cave 1	JVO_2	F*	M^1	-12.83	43.0	11.15	15.82.7	3.2	0.7104	0.0009
Jato Viejo	Cave 1	JVO_3	(M)	M^1	-15.79	43.7	9.00	16.02.7	3.3	0.710	0.0008
Jato Viejo	Cave 1	JVO_4	F	M^1	-15.05	41.9	10.79	15.32.7	3.3	0.7098	0.0008
Jato Viejo	Cave 1	JVO_5	F*	M^2	-16.96	43.3	8.68	15.42.8	3.3	0.7106	0.0009
Jato Viejo	Cave 1	JVO_6	(F)	M^2	-16.91	43.8	9.32	15.42.8	3.3	0.7105	0.0008
Jato Viejo	Cave 1	JVO_7	F	M^2	-15.79	44.7	9.14	16.12.8	3.3	0.7099	0.0006
Jato Viejo	Cave 1	JVO_11	M	M_1	-16.08	40.9	8.78	14.92.7	3.3		
Jato Viejo	Cave 1	JVO_12	M**	M_2	-15.80	41.6	8.88	15.72.6	3.0		
Ushcugaga	Cave 2	USH_2	F*	M_2	-13.62	43.6	9.17	15.92.7	3.3	0.710	0.0009
Ushcugaga	Cave 2	USH_3	F	M_3	-13.19	44.7	9.78	16.52.7	3.3	0.7101	0.001
Ushcugaga	Cave 2	USH_4	(M)	M_2	-13.77	44.4	10.32	15.62.8	3.3	0.7103	0.0006
Ushcugaga	Cave 2	USH_5	(F)	M_3	-13.07	46.4	10.39	16.92.7	3.3	0.7102	0.0008
Ushcugaga	Cave 2	USH_6	F	M_1	-13.97	46.4	8.87	16.92.7	3.3	0.7099	0.0005
Ushcugaga	Cave 5	USH_7	M	M_1	-14.11	44.6	9.32	16.12.8	3.3	0.7097	0.0005
Ushcugaga	Cave 5	USH_8	(M)*	M_1	-13.16	43.8	9.95	15.92.8	3.3	0.7125	0.0014
Ushcugaga	Cave 5	USH_9	M	M_2	-13.26	44.8	9.78	16.32.7	3.3	0.7123	0.0008
Ushcugaga	Cave 5	USH_10	M	M_1	-12.40	44.2	10.88	16.02.8	3.3	0.7095	0.0008
Ushcugaga	Cave 5	USH_11	(M)	M_1	-12.83	44.7	11.15	16.42.7	3.3	0.7096	0.0008
Ushcugaga	Cave 7	USH_13	M	M^3	-13.15	41.9	10.54	15.72.7	3.3		
Ushcugaga	Cave 7	USH_15	M	M_2	-13.96	42.7	9.62	16.02.7	3.2		

Ushcugaga	Cave 8	USH_16	(F)	M_1	-13.76	43.6	10.51	15.92.7	3.3
Ushcugaga	Cave 10	USH_17	M	M_2	-13.14	41.6	9.61	15.12.8	3.3
Ushcugaga	Cave 13	USH_18	F	M_1	-15.54	44.1	9.06	16.02.8	3.2
Ushcugaga	Cave 13	USH_19	F*	M_2	-15.53	42.3	8.89	15.32.8	3.4
Ushcugaga	Cave 13	USH_20	M	M_3	-14.57	43.3	9.30	15.62.8	3.3
Ushcugaga	Cave 14	USH_21	M*	M_1	-13.04	42.3	9.21	15.52.7	3.3
Ushcugaga	Cave 14	USH_23	F	M_1	-13.33	43.9	11.47	16.12.7	3.3
Ushcugaga	Cave 15	USH_24	F	M_1	-13.29	43.5	9.33	15.92.7	3.4
Ushcugaga	Cave 16	USH_25	(F)	M^1	-13.51	42.5	8.94	15.72.7	3.3
Ushcugaga	Cave 16	USH_26	M	M^1	-13.65	43.6	10.45	16.02.7	3.3
Ushcugaga	Cave 16	USH_27	F	M^2	-16.30	41.7	7.67	15.12.8	3.2
Ushcugaga	Cave 4	USH_28	M	M^1	-12.73	43.5	10.07	16.12.7	3.3
Ushcugaga	Cave 4	USH_29	M*	M^2	-13.15	45.0	10.30	15.62.9	3.3

Table S6.5: Sequencing statistics for the shotgun sequencing of the Marcajirca (N=32) , Jato Viejo (N=4) and Ushcugaga (N=6) libraries

Library ID	Sample	# reads	pairs merged	pairs adapters	M reads used	flagstats M reads mapped	M reads mapped, rmdup	ALL reads, rmdup, uniqly mapping	Avg length all mapped reads	% not duplicate	q20 %endo	% merged	Terminal Nucleotide Damage	Sex	XY Sex estimate (Skoglund)	RX Sex assignment	RX estimate	RX Conf interval
SC99_L1328	JVO_1	132023	102398	93867	102398	74326	73628	76458	62.8898	99.06%	56.2977663	77.56	5.7	**M**	consistent with XY but not XX	The sample should be assigned as Male	1.054604	0.9856428 1.123565
SC99_L1329	JVO_2	165889	109537	109622	109537	21048	20859	22133	59.8999	99.10%	12.6880022	66.03	3.2	**F**	XX	The sample should be assigned as Female	1.08883	1.026986 1.150674
SC99_L1330	JVO_5	159679	77599	76831	77599	22290	22100	47321	78.248	99.15%	13.9592558	48.60	7.7	**F**	XX	The sample should be assigned as Female	0.9976667	0.9416253 1.053708
SC99_L1331	JVO_12	473317	288858	399709	288858	197026	195321	197746	54.2957	99.13%	41.6266477	61.03	3.7	**F**	XX	The sample should be assigned as Female	0.5245284	0.4949457 0.5541111
SC93_L1258	MAR_9	456184	325892	344692	325892	180016	178497	181111	58.5641	99.16%	39.46127	71.44	1.7	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.5319052	0.5072535 0.5565569
SC93_L1257	MAR_8	1180525	683717	1018391	683717	224624	222819	216942	49.4368	99.20%	19.0274666	57.92	3.6	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.4896349	0.464948 0.5143219
SC93_L1259	MAR_11	906726	676889	464072	676889	83936	83286	93669	77.6272	99.23%	9.25704127	74.65	3.9	**F**	XX	The sample should be assigned as Female	1.081379	1.020624 1.142133
SC88_L1211	MAR_19	951006	800249	607951	800249	651	647	683	70.4056	99.39%	0.06845383	84.15	18.9	**F**	consistent with XX	The sample should be assigned as Female	1.258771	1.069057 1.448486
SC88_L1212	MAR_20	977994	840899	679362	840899	438	431	448	60.6739	98.40%	0.04478555	85.98	16.9	**n.d.**	consistent with XX	The sample should be assigned as Male	0.3992654	0.3537037 0.4448271
SC88_L1213	MAR_21	920138	754010	596383	754010	5825	5750	5869	58.8366	98.71%	0.63305722	81.95	17.5	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.504204	0.4802831 0.528125

SC88_L1214	MAR_22	895469	690574	644733	690574	30161	29831	32446	63.8839	98.91%	3.36817913	77.12	12.4	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.5190353	0.4897041 0.5483666
SC89_L1223	MAR_23	445270	324365	272245	324365	12639	12506	14121	65.9556	98.95%	2.83850248	72.85	14.4	**M**	consistent with XY but not XX	The sample is consistent with XY but not XX	0.5907461	0.5481665 0.6333257
SC89_L1224	MAR_24	724269	567698	474332	567698	3944	3909	4280	67.5021	99.11%	0.54454906	78.38	21.5	**F**	consistent with XX	The sample should be assigned as Female	1.109872	1.041196 1.178549
SC89_L1216	MAR_26	980344	807174	631519	807174	1372	1359	1372	56.0756	99.05%	0.13995087	82.34	19.5	**n.d.**	Not Assigned	The sample should be assigned as Male	0.4897031	0.4591529 0.5202534
SC89_L1217	MAR_27	898314	735894	634351	735894	21456	21209	20793	49.6496	98.85%	2.38847441	81.92	16.1	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.5183687	0.4801089 0.5566285
SC89_L1218	MAR_28	822891	701561	453677	701561	2079	2057	2231	64.7462	98.94%	0.25264585	85.26	11.4	**n.d.**	Not Assigned	The sample could not be assigned	0.6915346	0.6440149 0.7390542
SC89_L1220	MAR_30	1052582	853451	732263	853451	2021	1996	1998	53.886	98.76%	0.19200404	81.08	18.9	**n.d.**	Not Assigned	The sample should be assigned as Male	0.5424266	0.5170929 0.5677602
SC89_L1222	MAR_34	843291	672842	478676	672842	397	390	449	73.4183	98.24%	0.04707746	79.79	23.1	**n.d.**	consistent with XX	The sample is consistent with XY but not XX	0.6544466	0.5700784 0.7388147
SC93_L1261	MAR_37	478674	301648	336537	301648	51686	51207	52610	56.5417	99.07%	10.7977454	63.02	3.6	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.533736	0.499943 0.567529
SC93_L1262	MAR_38	297212	145277	208743	145277	42317	41966	45588	55.3798	99.17%	14.237985	48.88	3.1	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.5417007	0.5142339 0.5691674
SC93_L1263	MAR_40	131873	73145	88697	73145	252	250	278	67.3217	99.21%	0.19109295	55.47	3.1	**F**	consistent with XX	The sample should be assigned as Female	0.4730691	0.3630768 0.5830613
SC93_L1264	MAR_45	585809	417766	531791	417766	195603	193905	188636	46.3809	99.13%	33.3902347	71.31	3.9	**F**	XX	The sample should be assigned as Female	1.037316	0.9807293 1.093902
SC89_L1228	MAR_51	706119	579453	412633	579453	3759	3724	4028	68.9911	99.07%	0.53234653	82.06	19.2	**F**	consistent with XX	The sample should be assigned as Female	1.086201	1.010378 1.162023

SC89_L1226	MAR_52	776142	614370	460903	614370	89498	88451	90611	61.814	98.83%	11.5311373	79.16	13.6	**F**	XX	The sample should be assigned as Female	1.017977	0.9606466 1.075307
SC89_L1227	MAR_53	751313	595667	466295	595667	3843	3798	4512	73.0385	98.83%	0.51150453	79.28	12.1	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.6556902	0.6057796 0.7056008
SC89_L1225	MAR_54	809812	640330	533056	640330	164539	162655	162635	57.8741	98.85%	20.3181726	79.07	17.2	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.4884927	0.4647481 0.5122372
SC89_L1230	MAR_55	953342	778480	557865	778480	19630	19378	19380	58.2489	98.72%	2.05907219	81.66	10.2	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.5662504	0.5365321 0.5959687
SC89_L1229	MAR_56	896343	701958	478242	701958	5653	5596	5756	61.089	98.99%	0.63067375	78.31	13.8	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.4716939	0.4469219 0.4964659
SC89_L1231	MAR_57	965139	724059	654825	724059	73817	72895	71581	52.0286	98.75%	7.64832838	75.02	14.3	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.48101	0.4583252 0.5036949
SC93_L1265	MAR_59	69613	43147	55050	43147	3387	3360	3453	56.5749	99.20%	4.86547053	61.98	5.4	**n.d.**	Not Assigned	The sample should be assigned as Male	0.49863	0.4668446 0.5304155
SC93_L1267	MAR_63	341054	203942	261179	203942	1759	1747	1674	47.3625	99.32%	0.5157541	59.80	7.9	**n.d.**	Not Assigned	The sample should be assigned as Male	0.4226756	0.39201 0.4533413
SC93_L1268	MAR_64	203541	125308	136188	125308	13771	13649	15262	70.1183	99.11%	6.76571305	61.56	2.9	**F**	XX	The sample should be assigned as Female	1.032833	0.983251 1.082414
SC99_L1321	MAR_69	42276	21992	33664	21992	5090	5040	5127	56.7763	99.02%	12.0399281	52.02	2.9	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.4409366	0.4123175 0.4695557
SC99_L1324	MAR_84	56064	34201	27111	34201	7642	7570	10688	70.2483	99.06%	13.6308505	61.00	3.8	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.5335286	0.4853173 0.5817399
SC100_L1333	USH_19	212169	146298	85793	146298	11187	11089	12291	65.4001	99.12%	5.27268357	68.95	3.1	**F**	XX	The sample should be assigned as Female	1.09171	1.003192 1.180228

SC100_L1334	USH_2	237076	185101	152817	185101	18812	18658	21909	67.201	99.18%	7.93500818	78.08	9.4	**F**	XX	The sample should be assigned as Female	0.5712464	0.5298277 0.612665
SC100_L1335	USH_8	461176	353276	292534	353276	27032	26789	29355	70.9246	99.10%	5.86153659	76.60	2.5	**M**	XY	The sample should be assigned as Male	0.5625081	0.5262757 0.5987406
SC100_L1336	USH_21	431993	328625	256432	328625	82408	81662	94404	70.2291	99.09%	19.076235	76.07	3.6	**M**	XY	The sample should be assigned as Male	0.564279	0.5217083 0.6068496
SC100_L1337	USH_23	456563	345286	306749	345286	80179	79484	83585	63.1469	99.13%	17.5614318	75.63	3.2	**n.d.**	consistent with XX	The sample should be assigned as Male	0.5615634	0.5250016 0.5981253
SC102_L1353	USH_29	111134	72110	62103	72110	5335	5298	5883	67.6229	99.31%	4.80051109	64.89	9.7	**M**	consistent with XY but not XX	The sample should be assigned as Male	0.5511017	0.5170482 0.5851553

Supplementary Figures

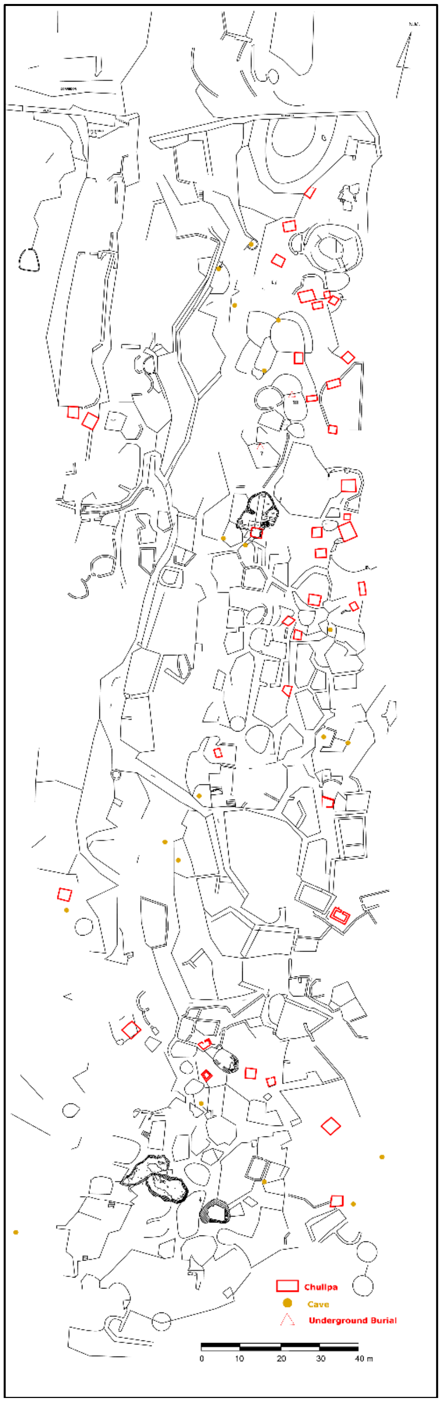

Figure S6.1: Map of the archaeological compex at the site of Marcajirca. The different type of burial contexts are highlighted in red.

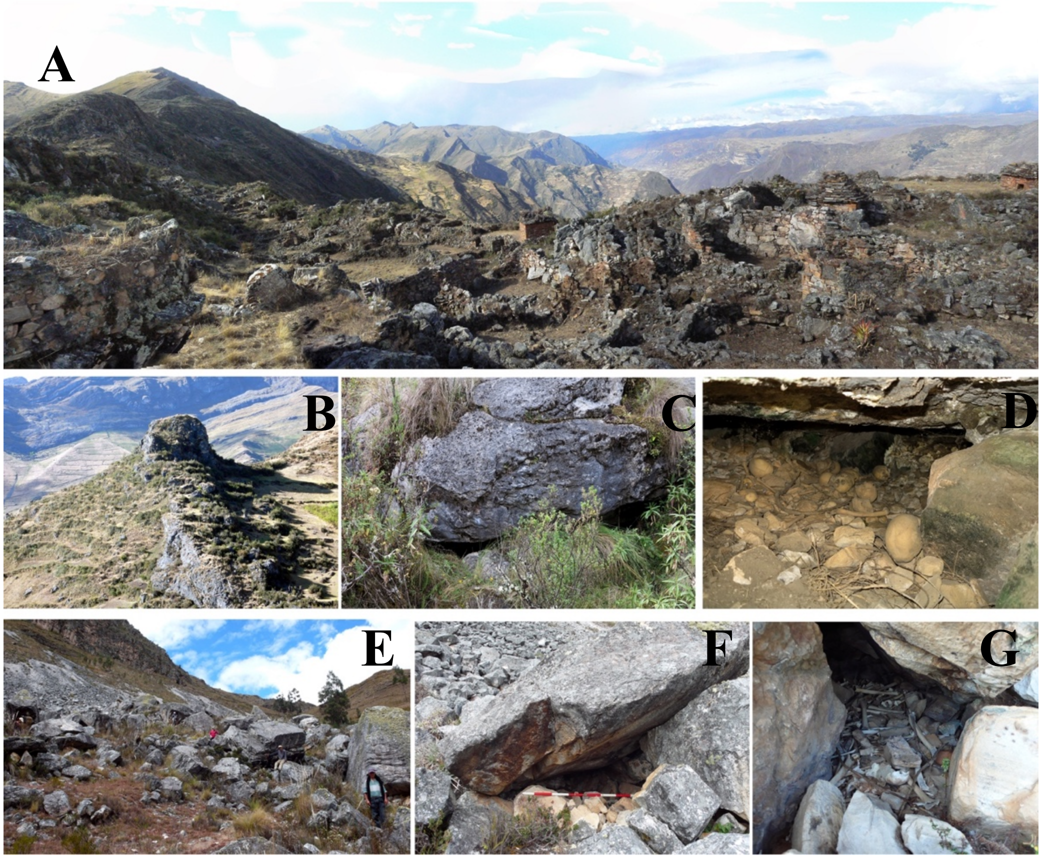

Figure S6.2: Photographs taken at Marcajirca, Jato Viejo and Ushcugaga. A) panoramic view from Marcajirca, B-D) Cave structures found at Jato Viejo; C) Modified entrance to Cave 1; D) commingled remains from Cave 1 (MNI = 10; Table S1), and E-G) Rockslide and cave burials found at Ushcugaga; F) Typical over hang created by rockslide where burials were placed (Average estimated MNI = 1-7 individuals; Table S1)

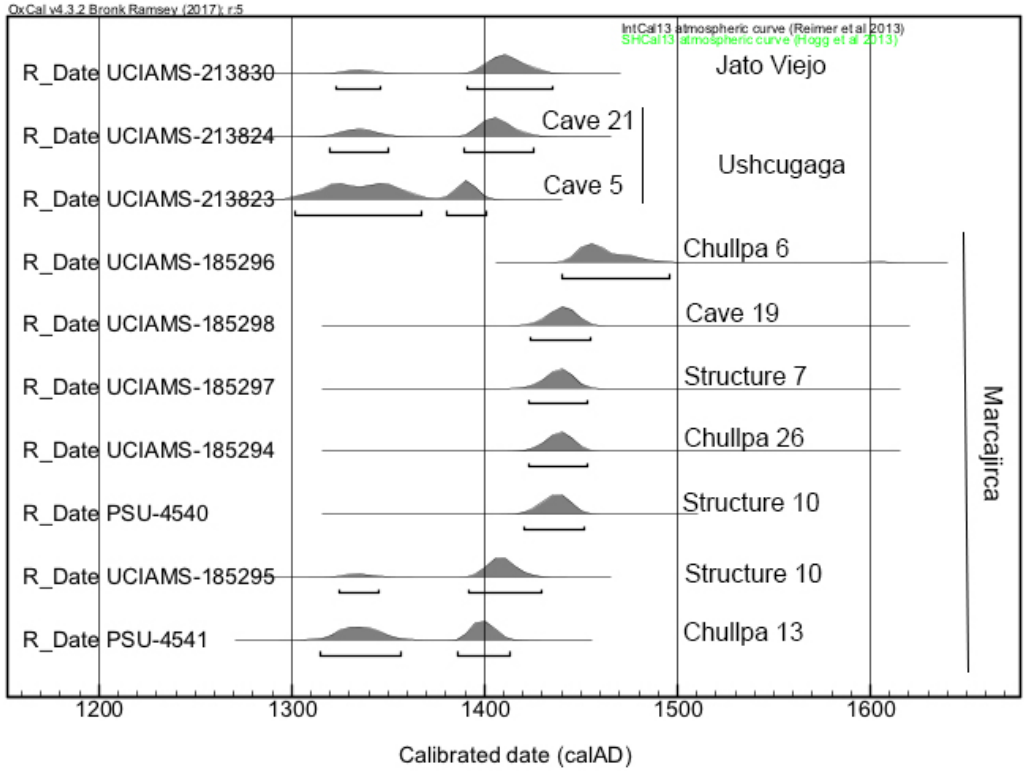

Figure S6.3: Calibrated radiocarbon dates from Marcajirca, Ushcugaga and Jato Viejo. Radiocarbon dates were calibrated with the mixed calibration curve (Marsh et al., 2018) using OxCal v. 4.3.2

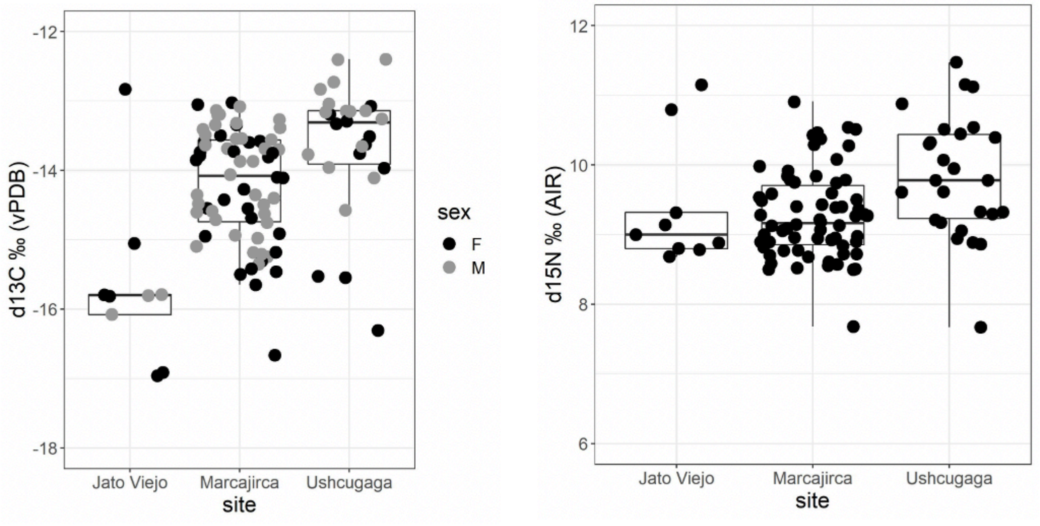

Figure S6.4: Results of full δ^{13}C and full δ^{15}N linear mixed models. A) δ^{13}C by significant site and sex. Individuals sexed without aDNA certainty were assigned male/female based on morphological characteristics and B) δ^{15}N by site

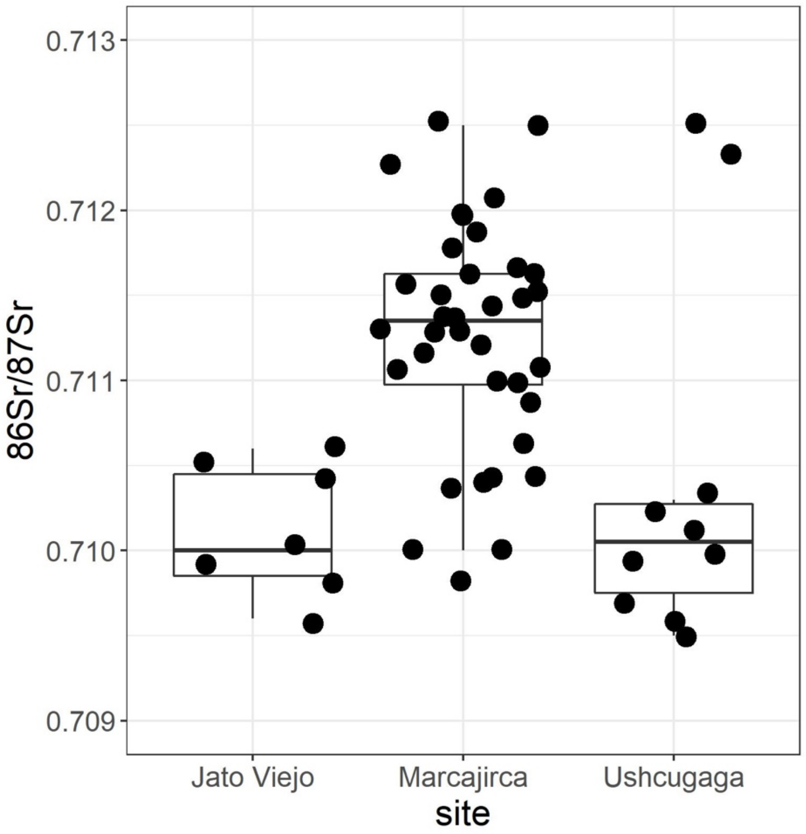

Figure S6.5: Results of full-null comparison for ^{86}Sr/^{87}Sr linear mixed model. ^{86}Sr/^{87}Sr by archaeological site

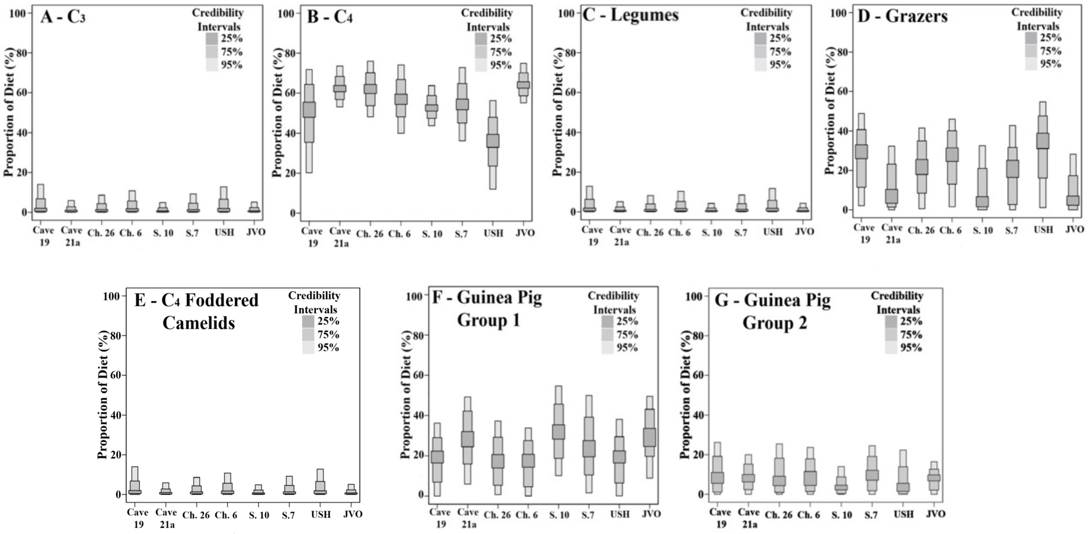

Figure S6.6: Results of several dietary mixing models on human diet by burial context for the sites of Marcajirca, Ushcugaga, and Jato Viejo shown for the seven main potential food resources im the region. 25, 75 and 95% credibility intervales are plotted for each burial context (see table S4 detailed description of each tomb context

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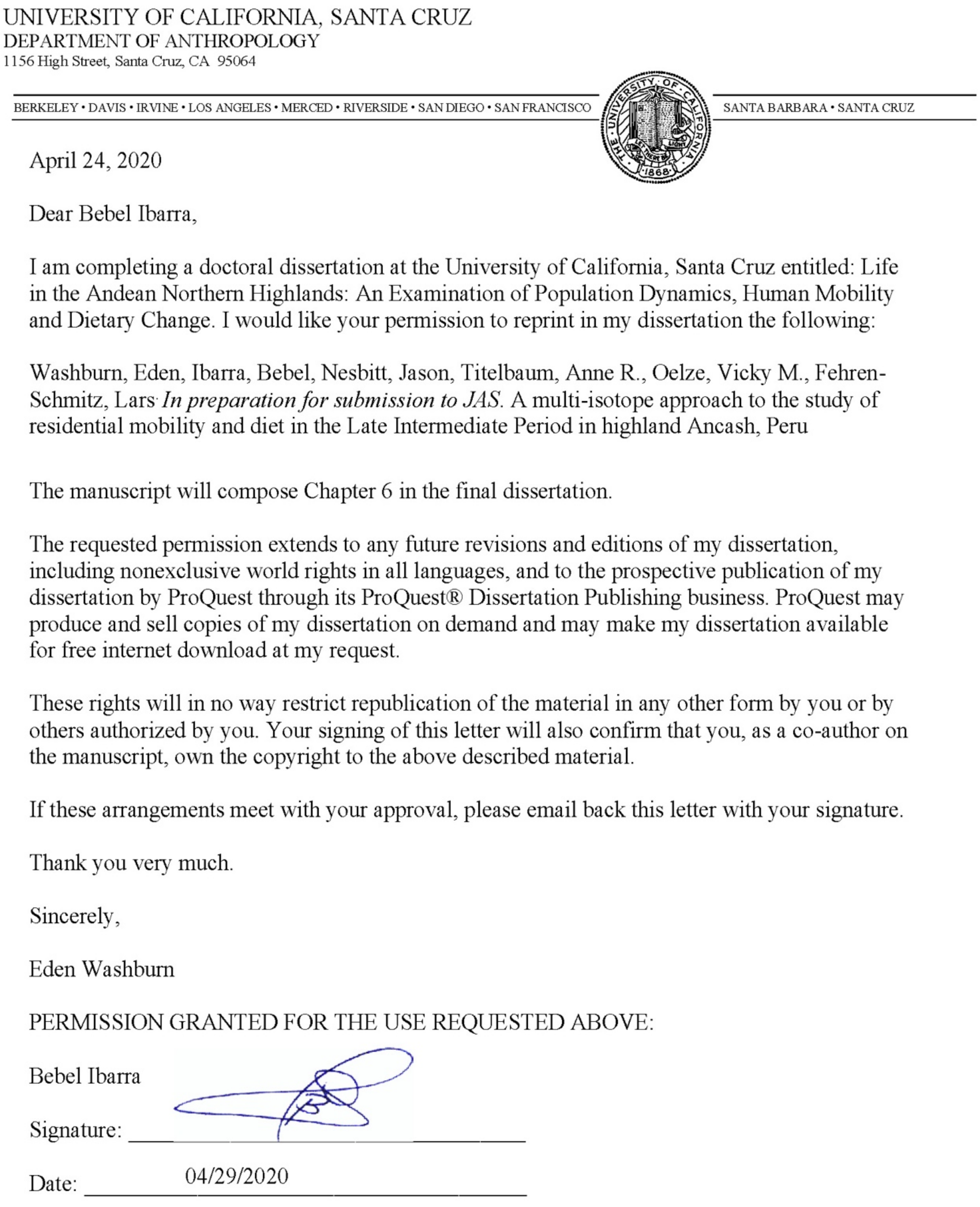

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CHAPTER 7

Conclusions and Future Project Directions

The landscapes found within the Department of Ancash, Peru are incredibly diverse, closely stacked and present inhabitants with a unique set of environmental demands. No landscape is perfectly suited to human habitation and as a result, humans learn, adapt to, transform or succumb to the pressures of their environment. But as a result of this process, humans are themselves changed in many interesting ways. The research presented in this dissertation focuses on how human populations, as they interact with each other and their environment, develop adaptive strategies to mediate environmental pressures, and how the overarching cultural atmosphere influences the choices and behaviors of people. This dissertation employs an interdisciplinary approach to the study of human-environment interaction that combines archaeology, osteology and stable isotope analysis. In this chapter, the two case studies outlined in this dissertation are used to discuss the plasticity of human responses to their physical as well as socio-cultural environments.

7.1 Case study 1: La Galgada, Peru Summary and Significance

During the Late Preceramic Period (c. 3000-1700 cal B.C.E.), groups living along the Peruvian coast and within the Andean highlands initiated the construction of monumental public architecture, associated with an increase in permanent settlements (Burger, 1992; Pozorski and Pozorski, 2018; Quilter, 1991; Solis et al., 2001; Washburn et al., 2020). This pattern continued into the Initial period (1700-800 cal B.C.E.), with a significant increase in the number of monumental centers, as well as the introduction of pottery technology (Burger, 1992; Pozorski and Pozorski, 2018; Washburn et al., 2020). In addition to greater degrees of sedentism, the Late Preceramic Period and early part of the Initial Period also underwent significant changes to the subsistence economy of Peru, with a growing reliance on cultigens like squash (Cucurbitaceae), beans (Fabaceae), manioc (*Manihot esculenta*), potatoes (*Solanum tuberosum*), and quinoa (*Chenopodium quinoa*), as well as wild game (Beresford-Jones et al., 2018; Caramanica et al., 2018; Coutts et al., 2011; Dillehay et al., 2005; Duncan et al., 2009; Moseley, 1975; Nesbitt, 2016; Perry et al., 2006; Pozorski, 1979, 1983; Pozorski and Pozorski, 1979; Quilter, 1991; Rumold and Aldenderfer, 2016; Washburn et al., 2020; Weir et al., 1988).

Located just a short distance from the Tablachaca River, La Galgada is situated in the hot and arid *Yunga* (at approximately 1,100 masl), where agriculture is only feasible through irrigation. The landscape is extremely rocky, and vegetation density decreases as distance from the riverbanks increases. Despite these challenges, the western *yunga* is highly productive and its warm climate permits the cultivation of tropical and low elevation crops (Onuki, 1985). The groups who built La Galgada most likely lived nearby to tend crops along the narrow belts of land straddling the Tablachaca (Grieder et al., 1988). La Galgada's location was advantageous due to its proximity to the agriculturally productive lands along the riverbanks, as well as its intermediate position for exchange between the coast and the highlands (Grieder et al., 1988; Washburn et al., 2020).

While La Galgada is not positioned at a significantly high altitude, the yunga presents several environmental challenges mainly relating to its hot and arid climate. Many varieties of wild crops do not grow in large numbers within this environmental zone, and rainfall agriculture is not possible due to the unpredictable rainfall cycles. Therefore, with the increase in sedentism and the proliferation of monumental centers within this landscape, groups adapted to their environment by developing irrigation agriculture, cultivating crops suited to the tropical climate and relying on a mixed economy based on plant domestication supplemented by hunting and fishing (e.g. Burger and van der Merwe, 1990; Quilter et al., 1991).

It has been argued that the domestication and cultivation of maize played an instrumental role in simulating the development of Central Andean complexity (e.g. Bonavia, 2008; Bonavia and Grobman, 1989a, 1989b; Haas et al., 2013; Kidder et al., 1963; Norr, 1995; Wilson, 1981). However, the growing archaeological record for the Late Preceramic and Initial Periods, including the results of my research, indicate that while consumed, maize was not an important crop in Peru until much later in time (Blake, 2015; Burger and van der Merwe, 1990; Burger, 2012; Pezo-Lanfranco et al., 2015; Pozorski and Pozorski, 1979, 2006; Seki and Yoneda, 2005; Shady, 2006; Staller et al., 2006; Tykot et al., 2006).

The adoption of maize agriculture seems to be largely culturally driven. Even in environments where maize is uniquely adapted as in the landscapes surrounding La Galgada, maize was not universally utilized; as my data suggests, there continued to be a reliance on locally available food sources. Thus, there are two main and important factors at play in the development of the subsistence strategies adopted by the inhabitants of La Galgada: a) the need to successfully subsist in an ecosystem constrained by environmental challenges, and b) the potential for culturally driven tastes and choices.

7.2 Case study 2: The Callejón de Conchucos Summary and Significance

My second case study differs from the first in time, altitude, number of archaeological sites, and location. The research for this second case study was conducted in the Conchucos, a high altitude, intermontane valley system suited on the southeastern side of the Cordillera Blanca, focusing on the archaeological sites of Marcajirca, Ushcugaga, and Jato Viejo that date to the Late Intermediate Period (c. 1000-1400 C.E.; LIP). Due to the differences in cultural time periods and the geographical distance between the two case studies, the results are not directly comparable, nor was it the intent of my dissertation to find linkage between them. Instead, the core question of my dissertation explores how humans adapt to their physical and cultural landscapes under differing circumstances.

In the Central Andes, the LIP was a time of cultural change. The LIP is often defined by scholars as the time in which much of the Peruvian highlands enters a period of political instability and fragmentation as a result of the collapse of the Wari and Tiwanaku polities of the previous Middle Horizon (600-1000 C.E.) (Covey, 2008; Lau, 2016; Martiarena, 2014). These cultural transformations are visible in the archaeological record and include physical anthropological indicators for trauma as the result of interpersonal violence (Brown Vega, 2009; Kurin, 2013; Langlie and Arkush, 2016; Rumold and Aldenderfer, 2016; Tung, 2008). Furthermore, in many parts of the Andean highlands, groups relocated and/or concentrated settlements to defensible locations at much higher elevations (~above 3,500 masl) (Bauer and Kellett, 2010; Bauer et al., 2010; Herrera and Lane, 2004; Herrera et al., 2007; Ibarra, 2009; Kellett, 2010; Larrain and Greco, 2018; Lofaro et al., 2018; Meddens and Branch, 2010). Yet, defense may not have been the only concern in settlement relocation. The movement of settlements off the valley floor to higher elevations also allowed greater access to the high-altitude *puna* grassland (3,900-4,500 masl)--a landscape rich in resources ideal for the grazing of domesticated camelids herds (llama and alpaca), and for the cultivation of tubers.

The results of this study indicate that subsistence practices in the Conchucos are directly tied to environmental productivity and the proximity to different ecological zones. At Marcajirca, located at 3,800 masl, diet appears to have been remarkably similar between all individuals tested.

Isotopic data from from this suggests that the individuals buried at Marcajirca, Ushcugaga and Jato Viejo had access to a variety of verticality stacked production zones and participated in an agropastoral pattern of subsistence. When comparing diet between the three sites, there are significant differences in $\delta^{13}C$ values which indicates a difference in the composition of the types of plants consumed. $\delta^{15}N$ values suggest elements of the diet were based on terrestrial protein, consistent with the consumption of terrestrial grazers like camelids, deer and/or guinea pig.

In addition to subsistence practices, this study examined differences in mobility patterns between the three archaeological sites. Based on the bioavailable $^{87}Sr/^{86}Sr$ range (0.7107-0.7126), estimated from local flora and fauna surrounding Marcajirca, 39% of all individuals measured from Marcajirca should liberally be considered non-local to the site, but not necessarily non-local to the Conchucos as geological formations with similar values are observed within the broader Conchucos. The vast majority of non-locals found at Marcajirca are observed in Structure 10, where 80% of all individuals have $^{87}Sr/^{86}Sr$ values that fall outside the established local range. The majority of enamel samples from Structure 10 come from either first or second molars, meaning these individuals were most likely not born or did not live at Marcajirca during early childhood. Questions remain about the origins of these individuals and their connections to Marcajirca. These questions will be addressed in future research projects.

The fact that Marcajirca is located at an altitude where all subsistence needs could not have been met suggests two likely scenarios that would result in the non-local $^{87}Sr/^{86}Sr$ values observed in some individuals from Marcajirca. First, the people themselves were practicing ecological complementarity; they themselves were moving around the landscape participating in daily activities like farming, animal husbandry and hunting. This resulted in the utilization of several larger production zones situated within distinct geological units of different ages and mean $^{87}Sr/^{86}Sr$

values. Second, trade networks were established in order to acquire foodstuffs from different production zones that were then incorporated into the diet

The archaeological site of Ushcugaga has a very different residential mobility pattern. At Ushcugaga, 80% of all individuals have $^{87}Sr/^{86}Sr$ values that fall outside the established bioavailable local range (0.7111-0.7133). This result is not unsurprising however, because to date there has been no habitation site found near the burials, indicating that the individuals interred at Ushcugaga were most likely brought to the site from some distance. In contrast, the majority of individuals found at Jato Viejo were most likely local to that site, where 100% of individuals have $^{87}Sr/^{86}Sr$ values within the local bioavailable range (0.709.2-0.7111). The differences in site function likely contributes to the differences in mobility patterns observed at Uschugaga and Jato Viejo.

Populations living at high altitudes experience both physiological (Baker et al., 1968; Baker, 1976; Beall, 2000; Frisancho, 1975; Lindo et al., 2018; Mazess, 1975a, 1975b; Moore et al., 1998; Moran, 2008) and environmental constraints (Brush, 1982; Contreras, 2010; Garreaud, 2009; Sandweiss et al., 2001; Sandweiss and Richardson, 2008; Strecker et al., 2007), including hypoxia (Aldenderfer, 1999; Aldenderfer, 2003; Dufour et al., 2014; Fehren-Schmitz and Georges, 2016; Rademaker et al., 2014; Weinstein, 2017), cold stress (Aldenderfer, 1999; Weinstein, 2014), aridity (Moran, 2008), shallow soils (Wilcox et al., 1988), steep mountain slopes, and low biological productivity (Moran, 2008; Rademaker et al., 2014). Populations have lived and coped with these inherent environmental constraints since the beginnings of human occupation. These regions have significantly complex distributions of ecological features that all affect human habitation, including the vertical distribution of resources, irregular biotic distribution, and geologic features such as steep mountain slopes and rugged terrain. The Andes mountains contain a rich diversity of ecological zones with vegetation and climatic zoning distributed vertically along the mountain slopes (Figure 7.1). With increased elevation rapid changes in vegetation and animal life occur; on any given mountain, it is possible to have four or five major ecological zones present.

As a result of this vertical distribution of resources, human populations in the Andes have developed an adaptive strategy that facilitates access to different elevation zones and the resources found within each. First proposed by John V. Murra, the ‘verticality’ or ‘ecological complementarity’ model (Lau, 2016; Lynch, 1980; Moseley, 2001; Murra, 1972) describes the innovative use of multiple ecological/altitudinal zones for resource acquisition.

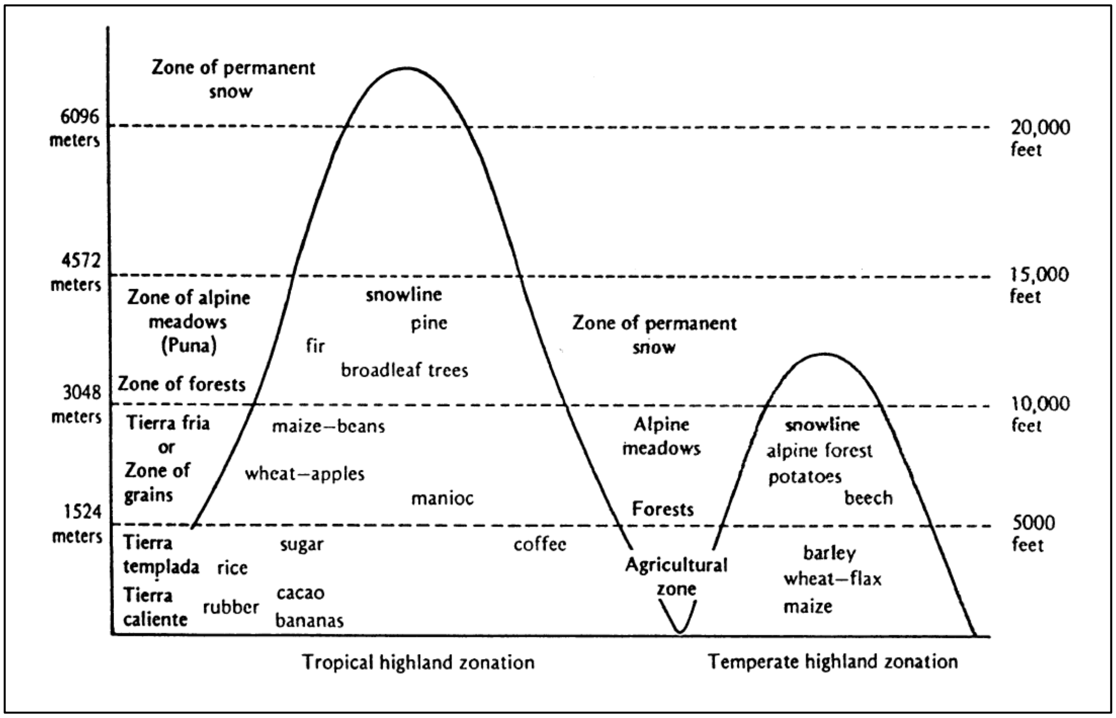

Figure 7.1. Zonation and the distribution of resources based on altitude (Moran, 2008: 161)

In the Conchucos for example, archaeological sites like Marcajirca, Ushcugaga and Jato Viejo are positioned in locations with strategic access to the high altitude *puna,* ideal for grazing camelid herds and the cultivation of high altitude adapted tubers while still maintaining access to lower altitude mountain slopes that are well suited for the cultivation of maize and manioc (*Manihot esculenta*). These sites also provide proximity to the valley floor that is generally best suited for the cultivation of agricultural plants such as squash (Cucurbitaceae), beans (Fabaceae), a variety of potatoes (*Solanum tuberosum*), quinoa (*Chenopodium quinoa*), coca (*Erythroxylum coca*), and peanuts (*Arachis hypogeal*).

The high proportion of C_4 plants and animal protein in the diet of individuals interred at Marcajirca, Ushcugaga and Jato Viejo indicate that to a certain degree these populations were utilizing an ecological complementary subsistence pattern, with the sites strategically placed in locations with access to a wide range of altitudinal zones. In addition to similarities in the diet between sites, the mobility patterns observed suggest the definition of local [vs non-local] should be expanded to include the entire valley as a system. As individuals moved throughout the landscape within the Conchucos moving up and down mountain slopes, they would have crossed or accessed resources from multiple geologic formations. The groups of people living in the Conchucos had to live under challenging environmental constraints but also during a time coping with little political stability. The strategic locations in establishment of these archaeological sites seemed to have served multiple life-sustaining functions including providing access to multiple ecological zones for subsistence, with the potential for defensible space under social, political and economic conditions where this may have been necessary.

7.3 Methodological Take-Aways

A key component of my dissertation research is the study of past human mobility through the use of $^{87}Sr/^{86}Sr$ stable isotope analysis. However, the use of $^{87}Sr/^{86}Sr$ isotope analysis to identify the potential origins and movement of individuals in the archaeological record relies on an accurate characterization of local $^{87}Sr/^{86}Sr$ ranges. When using this method, it can prove to be insufficient to solely document the $^{87}Sr/^{86}Sr$ variation in an archaeological assemblage of human remains if no environmental $^{87}Sr/^{86}Sr$ baseline data is available to compare with human values.

In other words, it was necessary to create a regional $^{87}Sr/^{86}Sr$ isoscape (a spatially explicit prediction of isotopic variation across a landscape) that maps the strontium isotopes found within living systems for every geological formation within the region, because the extent of $^{87}Sr/^{86}Sr$ variation had not yet been studied.

This study, while fundamentally important for the interpretation of human $^{87}Sr/^{86}Sr$ values, also sparked my critique of past $^{87}Sr/^{86}Sr$ isotope studies and led to the methodological critique discussed in Chapter 5. In that chapter, I illustrated the need to include all geological formations accessible to humans in order to document the full extent of possible $^{87}Sr/^{86}Sr$ values in a given region. As a result of my research, I now present the largest regionally specific, bioavailable $^{87}Sr/^{86}Sr$ map (2,640 km^2) to date of the Peruvian Andes as a future baseline for archaeological case studies in this part of the Andes.

In the Andes, $^{87}Sr/^{86}Sr$ analysis has been used to address a range of questions about human mobility and adaptations to the Peruvian highlands (Andrushko et al., 2009; Bethard et al., 2008; Buzon et al., 2012; Chala-Aldana et al., 2018; Conlee et al., 2009; Knudson, 2008; Knudson et al., 2004, 2009, 2016, 2017; Knudson and Tung, 2007; Knudson and Buikstra, 2007; Knudson and Tung, 2011; Kurin, 2016; Lofaro et al., 2018; Mader et al., 2018; Marsteller et al., 2017; Slovak et al., 2009; Slovak et al., 2018; Standen et al., 2018; Stanish et al., 2018; Tung and Knudson, 2008, 2011; Turner et al., 2009; Turner and Armelagos, 2012). The vast majority of $^{87}Sr/^{86}Sr$ isotope studies are situated along the Pacific coast, in the southern Andes and west of the Cordillera Blanca, even though dynamic human occupation has a deep history throughout the Central Andes (Burger, 1992; Lau, 2016; Nesbitt et al., 2020; Quilter, 2014). The lack of $^{87}Sr/^{86}Sr$ studies within highland valley systems, particularly east of the Cordillera Blanca, has resulted in the under-estimation of the geologic complexity throughout the region, impacting the effectiveness of extrapolating $^{87}Sr/^{86}Sr$ values for these regions. This geological complexity means that distinguishing people of local versus non-local origin at a given site or region remains both promising and challenging. To increase the effectiveness of this method, I argue that regionally-specific $^{87}Sr/^{86}Sr$ studies should emphasize the collection of environmental samples of biologically available $^{87}Sr/^{86}Sr$,.

7.4 Future project directions

The research presented in this dissertation has illuminated many multi-faceted aspects of daily life in the Peruvian Andes, and provided new insights into human-environment interactions, mobility, and subsistence practices. However, it has also resulted in additional questions that still need to be addressed surrounding human life history, how populations interacted with one another, and if the patterns observed are also present in earlier time periods. In order to address these questions, additional data analysis and the incorporation of new research methodologies (i.e. ancient DNA, oxygen isotope analysis, etc.) is necessary. Our further research questions include:

7.4.1 Age at Weaning Study

As noted previously, an interesting outcome of my research at Marcajirca, Ushcugaga and Jato Viejo are the potential differences in age at weaning and/or early childhood diet between the three archaeological sites. Studies show that duration of breastfeeding and early childhood diet is critical in individual development. Breastfeeding and early childhood diet help establish the oral and gut microbiomes, set the body's metabolic trajectory, prime the immune system, and may even affect cognitive development (e.g., (Eerkens et al., 2017; Hinde and Capitanio, 2010; Kau et al., 2011; Kennedy, 2005; Li et al., 2008; Lönnerdal, 2000; Wadsworth et al., 1998). These factors play a critical role in determining overall health, and are measurable in the bioarchaeological record, including stature, life expectancy at birth, and various pathological conditions and nutritional stress indicators (Eerkens et al., 2017).

Additionally, age at weaning is an important measure of investment by parents in their offspring. Prolonged breastfeeding by mothers is a trade-off between investment in the current infant, investment in her own well-being, and future reproduction. Breastmilk provides a reliable and easily digestible source of macro-, micro-nutrients and pathogen-free water. At the same time, its production represents a significant energetic investment, requiring 500-700 kilocalories of additional food per day (Eerkens et al., 2017; Lönnerda1, 1986; Thomson et al., 1970). Provisioning children with food also constitutes an investment by one or both parents, with tradeoffs between energetic costs, opportunity costs (of having or supporting more children), and child safety (if children are foraging on their own). Reconstructing weaning and early childhood diet in ancient populations can inform on a number of interesting and inter-related anthropological issues, including parental investment, foraging decisions, population growth, and general human health (Barry and Paxson, 1971; Choy et al., 2010; Crittenden et al., 2013; Fuller et al., 2006a; Fuller et al., 2006b; Hill, 1993).

Work toward the accumulation of this data has already begun and this study represents a continuation/expansion of my dissertation research. In collaboration with Dr. Jason Nesbitt and Bebel Ibarra, 110 first molars were studied from numerous archaeological sites within the Conchucos. These teeth were sequentially sampled; a sampling process that involves extracting collagen from serial sections within restricted areas of a tooth that represent different periods of time and stitching together isotopic information from these sections (Figure 7.2) (Eerkens et al., 2017). $\delta^{13}C$ and $\delta^{15}N$ isotope values have already been measured at the UC Santa Cruz Stable Isotope Facility and data analysis is the next step for this project.

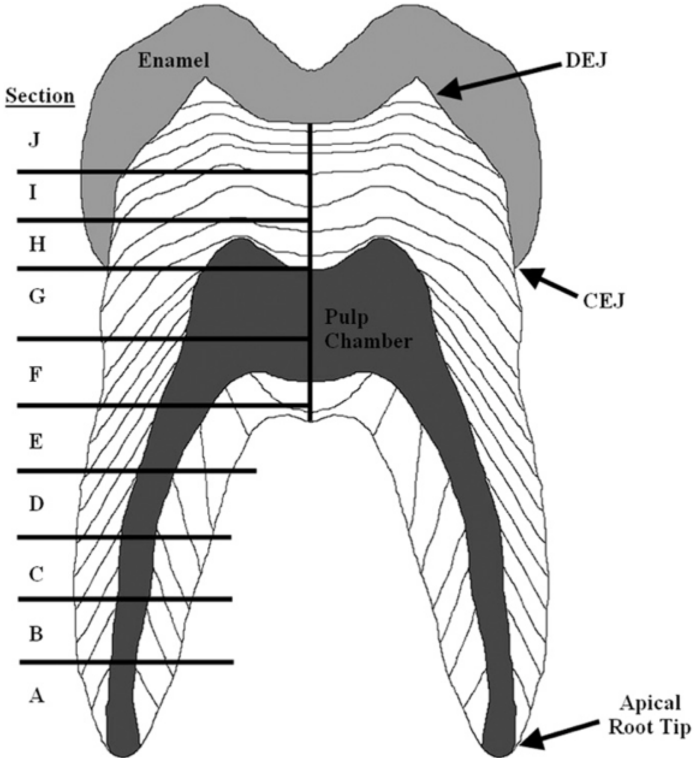

Figure 7.2: Serial sampling strategy used in this study, showing tooth landmarks on the right and horizontal serial samples on the left (Eerkens et al., 2017)

7.4.2 Ancient DNA

Question: Did changes in cultural dynamics affect mortuary practices at Marcajirca

In a subsistence-based community, individuals are faced with daily life-and-death challenges. The availability of natural resources for subsistence is just one aspect of life that could have been altered by cultural changes both internally and externally. Additionally, with death as an important feature of identity for societies, funerary practices become a significant expression of cultural change and interaction (Bloch and Parry, 1982).

Three types of burial structures are present at Marcajirca: chullpas, caves, and in-ground internments. There are many differences between these burial types, and even individual structures of the same type show fundamental differences. The term “chullpa” refers to a type of burial house or above-ground tomb. Amongst the chullpas found at Marcajirca there are significant differences in architectural style, including stone type, inside area, height, and roof design. Some chullpas are small and display a rougher, more unpolished construction (lower investment), while others are quite large and built with finer masonry of better-polished and thinner stones (higher investment). Generally, the chullpas have a small entrance, usually 40 by 50 cm, and tomb accesses were not covered, leaving the entrances open. This may indicate their continued use both as a tomb and as a location for continual ancestor veneration and the presentation of offerings. These chullpas are on average 1.20 by 1.50 meters, and each has a Minimal Number of Individuals (MNI) of more than 20 (Ibarra, 2003, 2006, 2009, 2013).

Similarly, some caves exhibit man-made elements, including a stone entrance, partial roof construction, or interior wall construction, while others appear to consist of only naturally occurring elements. Thirty-six chullpas of varying types have been identified in both the residential and funerary sectors, indicating that chullpas served as the primary burial structure for the population of Marcajirca. In addition, there are 19 cave burials as well as at least two in-ground interments.

It is unclear whether caves, chullpas, and in-ground internments served the same funerary function. It has been hypothesized that chullpas were cultural creations of the community and that each chullpa belonged to a specific kin group, known as an ayllu. Ayllus can range in size and can be hierarchically ranked (Isbell, 1997). Additionally, little research has been done on the use and function of burial caves in the northern highlands. Based on the placement of both caves and chullpas in spaces closely associated with residential structures, a preliminary hypothesis assumes that burials in both structures followed a system based on kinship or social relations.

Through the archaeological data alone, the organization of burial structures is still a mystery. This new research direction aims to untangle how each burial type was used and to address questions of lineage ownership using aDNA. Previous radiocarbon dates suggest that there are burials that date to the LIP, Late Horizon, and Early Colonial Period that can be used to investigate cultural influence on the individuals who were buried in each type of structure as well as potential admixture events resulting from Inca and European colonialism.

Question: Is there evidence of population continuity or discontinuity at Marcajirca and in the Concuchos?

Because of the differing levels of political stability and instability throughout the LIP, Late Horizon, and Early Colonial Period, questions about population continuity and discontinuity become important in order to understand the large-scale effects of these changes on and within a community.

The site of Marcajirca was constructed during the LIP at a time of regional instability, evidenced by the development of independent regional polities and an increase in rates of cranial trauma at Marcajirca (Pink, 2013; Titelbaum et al., 2015). There are two potential groups that could have been associated with the construction and occupation of the site, the Hubris and the Pincos. These two ethnic groups are not distinct enough genetically to distinguish using previously applied methods and currently published data. However, by utilizing the methods described below, in conjunction with the unpublished genetic data from all samples throughout the Andes (collected by Dr. Lars Fehren-Schmitz and colleagues) showing a distinct genetic structure among populations of the northern and central Andes and the Cusco region to the Titicaca Basin present as early as the Early Horizon (900-200BC), it may be possible to begin to identify a pattern of interaction not previously documented. *For example, was the population made up of one main group, or is there evidence that people from diverse genetic backgrounds migrated to the site after the collapse of the Wari Empire?*

Inca presence is evidenced in and around the Puccha River Valley by the Inca Road, regional centers, Inca architecture, and material culture. At Marcajirca, Inca influence is indicated by the presence of Inca material culture as well as a very large and distinct chullpa, constructed in a common Inca architectural style placed at the center of the site. However, the extent of Inca influence on and physical presence in the communities living in this valley remains unclear. Through aDNA analyses, the proposed project will address questions of how the Inca managed groups living in this region, that is, whether by distinct physical presence or by more remote supervision. Due to the distinct genetic signatures between individuals from the Inca heartland (documented by Dr. Lars Fehren-Schmitz and colleagues – not yet published), geneflow from the Inca into the Puccha Valley should become evident when comparing individuals from Marcajirca and Soledad de Tambo an Inca provincial site located in the Puccha River Valley, due either to admixture (people reproducing with each other) or to distinct genetic clusters when comparing non-Inca with Inca.

Archaeological evidence, as well as colonial documents, suggest that the collapse of the Inca Empire brought back the resurgence of small and distinct communities, where some groups living at large sites, such as Marcajirca, may have dispersed and moved to settlements at lower altitudes. For those that remained at sites like Marcajirca, this change in political structure would have disrupted daily subsistence practices and may have forced groups to adopt a more localized resource acquisition strategy. Again, depending of the resolution of data, this research will address questions of population change and movement to and away from the site during this transitional period.

From the colonial history of the Ancash, it is evident that the highlands of the Conchucos Mountains (where the Puccha River Valley is located) were among the first access routes between North Peru and Lima during the Spanish Conquest (Ibarra 2003a, 2003b, 2009a). This is one of the reasons that the remote highland Ancash landscapes were described in detail throughout different historical documents. For example: Miguel Estete's description of the Cordillera Blanca during Hernando

Pizarro’s expedition (1533AD), from Cajamarca on the north coast to Pachacamac. "Ancash" is also mentioned in other documents: Pedro Cieza de León, who travelled in the region in 1547, Vazquez de Espinoza’s description in 1629, and the chronicles of Fray Juan Meléndez, who traveled to Chavín and Huari in 1631 (see Tesoros Verdaderos de las Indias). While colonial encounters between native populations and the Europeans are documented through the lens of the colonizers, the impact of colonization on the organization of populations and the occupation of high-altitude sites is not. The site of Marcajirca was occupied through the beginning of the Early Colonial Period, and individual burials dating to this time period provide a unique opportunity to understand the effects of pre- and post-physical contact interactions.

Question: What is the relationship between highland and lowland Amazonian populations?

The Peruvian Northern Highlands and specifically the Conchucos region has a rich cultural history with many archaeological sites yet to be fully documented or studied. With my collaboration with Dr. Richard Burger (Yale), Dr. Jason Nesbitt (Tulane University), Bebel Ibarra-Ascencios (Tulane University), and the broader Huari-Ancash Bio-Archaeological Research Project, I have the opportunity to expand my bioanthropological study of human populations in this region. My future research will include an expansion into the Marañón River Basin to study the connections between highland and lowland Amazonian populations, an aspect of interaction not addressed in my dissertation. This region is known as the “Andean-Amazonian

Divide; a conceptual division used to reference the geographical as well as potential cultural separation between the high peaks of the Andes and lowland Amazonian landscapes. As a result of this conceptual separation little is known genetically or isotopically about the connections between these two distinct environments and their inhabitants.

7.4.3 Stable Isotope Analysis

Expansion of strontium isoscape

In conjunction with my interest in growing my research to include additional samples from within the "Andean-Amazonian Divide," I plan to add to my existing strontium geological map to include samples from deeper into the Marañón River Basin and further east into the Amazon, a region where little is known about geology and its inhabitants. This will allow my research to potentially identify the origins of individuals whose strontium isotopic signatures do not match the local highland geology. This expanded map can then be cited in future strontium isotope projects as both a source of data, and as a model, for strontium isotope projects in other regions.

Launch a large-scale oxygen isotope study

Oxygen isotopes (like strontium) can be used to track human mobility across landscapes. Oxygen isotope ratios of human body tissues, expressed as $\delta^{18}O$, are strongly related to the consumption of drinking water. Water $\delta^{18}O$ values vary with geographic region as a result of hydrological, geographical and climatological factors. It has become a widespread practice to use $\delta^{18}O$ values measured in human and animal dental enamel and compare to these data with mapped $\delta^{18}O_w$ groundwater values to locate the region where the owner of the tooth lived during the formation of the enamel. In the Andean highlands however, some questions still remain about the feasibility of using oxygen as a proxy for mobility, including the mobility of water through the environment and annual variability of precipitation. My planned research will involve collecting groundwater samples, testing the $\delta^{18}O$ values and creating a map of the variation found in $\delta^{18}O$ values in the North Central Highlands. I will then analyze $\delta^{18}O$ values of human tooth enamel from archaeological sites in the region.

7.4.4 Expand my research to include sites from earlier time periods

For purposes of my dissertation it was necessary to limit the scope of my project. I am now looking forward to expanding my research collaboratively with my colleagues to address similar questions in earlier time periods. Recently, human remains have been found at the archaeological site of Canchas Uckro. This site dates to (1100-800 cal B.C.E.) and seems to have been abandoned just prior to the intensified monumental construction of Chavín de Huantar, the epicenter of a religious movement that spread throughout the Andean Highlands. I have personally collected samples of the human remains found at Canchas Uckro, in collaboration with lead archaeologist Jason Nesbitt (Tulane University), and I am excited to begin the analysis of these samples.

7.5 Final Thoughts

This research has sought to analyze how humans interacted with their environments, their subsistence practices, the ability of groups of individuals to move throughout the landscape, and how these populations interacted with one another. The environment of the Andes is truly spectacular in many ways, but also presents inhabitants with a unique set of challenges to overcome. This research has shown that the people living in this environment adapted, transformed, and successfully occupied these landscapes, all while creating and navigating an incredibly dynamic socio-cultural landscape. The data presented in this dissertation only provides a glimpse into the daily lives of these people, but it is important to remember and be mindful that people are and should be the focus of this research; they lived each day, struggled, thrived, developed interpersonal relationships, and ultimately lived their lives through all their circumstances utilizing their available resources.

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