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Pre-Hispanic Frailty and Mortality in the Lambayeque Valley: Wilson Bands as Evidence of Early Life Stress

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Pre-Hispanic Frailty and Mortality in the Lambayeque Valley: Wilson Bands as Evidence of Early Life
Stress

by

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Under the Direction of Bethany Turner, PhD

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

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ABSTRACT

Early life stress impacts frailty and is important for understanding mortality in ancient populations. Utilizing Wilson bands (WB) from enamel thin-sections, this thesis explores displays of phenotypic plasticity, early life stress between pre-Hispanic and Colonial samples, and osteobiographical accounts of individuals associated with the Formative (3200-200BCE, n=2), Late Moche (550-800CE, n=11) and Late Sicán (1100-1375CE, n=1) periods from the Ventarrón archaeological complex in northern coastal Peru. Late Moche individuals had high prevalences of WB, potentially linking low socioeconomic status to acute, episodic early childhood stress. Pre-Hispanic individuals with WB displayed greater frailty and earlier mortality than those without, indicated by lower average ages at death. Differences in WB prevalence between these Ventarrón cohorts compared to previously studied Colonial cohorts by Garland et al. (2016) showcase the importance of not treating pre-Hispanic cultures as an unchanging monolith. Future studies expanding this database will provide a more nuanced understanding of these patterns.

INDEX WORDS: Wilson bands, Pre-Hispanic, Bioarchaeology, Stress, Lambayeque

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DEDICATION

This thesis has been an equal labor of love and frustration and would not have been possible without the support and encouragement of my friends and family. To the Possum Posey, who kept me laughing and going even when I was tempted to drop out and move to Saskatchewan. To the Former Commune, who supplied me with endless cat and plant snaps. My cat, who kept me company well into the night as I worked on writing and analyses. He should honestly be considered a co-author. My grandfather, who will not have the chance to read my thesis but was so proud of what I was doing. And most of all my parents, who have let me lurk about their basement the past two years reading and writing and mumbling things about “teeth” and “wait, how many names does this site have?” Without their endless support, I would not be here today.

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1 INTRODUCTION

1.1 Overview

Today, the word “stress” evokes thoughts of deadlines, a visit from one’s in-laws, or the news. These stressors are a mental reaction to an unpleasant reality and, while important, are not the focus of this thesis. Instead, this thesis focuses on stressors that stem from the environment and the ways that they imprint themselves on the human skeleton. Like everything else in the world, a human has finite resources and energy to maintain homeostasis. The depletion or reallocation of these resources, such as through undernutrition or disease burden, can disrupt the growth and maintenance of tissues (Moran, 2008, p. 8). Disruptions preserved as lesions on skeletal elements survive through time to be studied by bioarchaeologists today. To view humanity as powerless figures in the face of environmental constraints and difficulties would be incorrect. Utilizing cultural adaptations, humans have not only buffered themselves against environmental stressors but have in turn modified the environment to better suit their needs. For instance, the advent of agriculture in many parts of the world has reshaped the landscape and produced a surplus of food to support an urban environment (Algaze, 2001).

Of course, not all cultural adaptations buffer against stress. Indeed, some serve to exacerbate it. Some factors, such as war or political upheaval, may both be caused by and result in short-term periodic decreased access to resources (McMichael, 2012). Others, including socioeconomic inequality, are based upon religion, profession, ethnic identity, and kinship groups, and result in differential access to resources over the span of a lifetime or generations (Gijseghem, 2001; Klaus, Harvey, & Cohen, 2017; Klaus, Shimada, Shinoda, & Munro, 2017; Rosello, Vasquez, Morales, & Rosales, 2001; I. Shimada, Shinoda, Farnum, Corruccini, & Watanabe, 2004). Typically, lower socioeconomic status results in decreased access to resources. Place of residence also impacts the stress one is exposed to. Urban dwellers tend to live in closer contact with neighbors and may have problems discarding waste, enabling the rapid spread of some diseases (Moore, Gould, & Keary, 2003). Rural dwellers often live in closer contact with animals

and are thus exposed to more zoonotic diseases (Hotez, Savioli, & Fenwick, 2012). As a result, two populations in a given region—facing similar environmental constraints and utilizing the same resources—may still be differentially exposed to stress. Even those exposed to an identical stressor may experience it differently. Inherent genetic differences and the experience of an additional or concurrent stressor early in life can result in frailty, which can cause some individuals to become more affected by a stressor than others (Wood, Milner, Harpending, & Weiss, 1992).

The Lambayeque Valley Complex, located on the north coast of Peru, is an ideal place to study the interactions of humanity and the environment. Like the rest of the Central Andes, the Lambayeque Valley Complex is a challenging environment in which to survive and make a living. The arid coastal desert is punctuated by fertile river valleys. The region experiences frequent droughts and flooding, which have resulted in desertification of arable land over the past 12,000 years and the destruction of fields and cities. There is also the occasional earthquake or volcanic eruption to wreak havoc as well. At higher altitudes, thin soils and steep inclines require specialized farming techniques. These environmental constraints can make growing or procuring food difficult, which can result in nutritional deficiencies and a resulting greater susceptibility to disease (Moseley, 2001; Shimada, 1994b).

Simultaneously, this region also offers ample resources for human populations to exploit. The cold Humboldt current off the coast, which drives the atmospheric temperature inversion producing desert conditions, simultaneously provides a rich upwelling of nutrients, creating the richest marine ecosystem in the world (Cane, 1986). The rapidly increasing altitude of the Andes results in diverse, vertically stacked ecological niches that support a wide variety of plants and animals including potatoes, maize, cotton, camelids, and more (Shimada, 1994b; Turner & Klaus, 2020, p. 39-42). Along the river valleys, periodic flooding helps to deposit nutrient-rich soils along the banks of the rivers (Sandweiss & Maasch, 2020). The north coast of Peru has a long history of occupation, likely beginning around 14,500 years ago and continuing to today (Dillehay, 2017). A broad history of the region can be characterized by

two major processes: the slow adoption and growth of sedentary agricultural lifeways roughly spanning from 13,000 years ago to 4200 BCE and the arrival of the Spanish in 1532 CE, both of which irrevocably changed patterns of living (Lambert et al., 2012; Turner & Klaus, 2020, p. 67). Significant changes in lifestyle, religion, and technology also developed over the millennia among the many changing cultures that called the north coast home (Jennings, 2008; Moseley, 2001; Shimada et al., 2004).

By using cultural adaptations, past populations were better able to extract and utilize the abundant resources available, buffering themselves against what could be a hostile environment. For instance, irrigation canals managed by kinship groups opened up more land for cultivation (Dillehay & Kolata, 2004; Hayashida, 2006). Horizontal and to a lesser extent vertical kinship-based trade networks extended through the valleys, enabling the flow of resources (Shimada, 2001). In addition, long-distance trade among local and far-flung regions via camelid caravans or boat moved necessary resources around (Dufour et al., 2014; Saintenoy, 2016; Shimada, 1981; Vogel, 2017). Camelid domestication provided not just a means for transportation, but also resources like wool for textiles and meat (Dufour et al., 2014). The domestication of maize generated a durable crop that could be stored in times of need (P. M. Lambert et al., 2012). These cultural adaptations, amongst others, were utilized by north coast populations and served as buffers against environmental stress.

Although many cultures have resided in the Lambayeque Valley Complex, the Moche remain prominent in the archaeological record. The Moche occupied much of the north coast of Peru from approximately 100-850 CE. The Moche realm consisted of two separate polities, one in the north and one in the south, united in their religion, ceramic styles, and overall rule of Moche elite (Benson, 2012; Chapdelaine, 2011; Klaus, Alva, Bour, & Chero, 2018; Quilter, 2002, 2020). The southern polity reached the height of its sociopolitical power around 300-550 CE and was centered in the Moche and Chicama Valleys. It is argued to have been more of an ultra-complex paramount chiefdom with a central administrative center, also called Moche, presiding over the region (Benson, 2012; Chapdelaine, 2011).

The northern polity during this time consisted of numerous, smaller communities that were either allied with the south or were quasi-independent and subject to the south (Chapdelaine, 2011; Koons, 2015; Quilter, 2002). Following the decline of the south in 550 CE, the north became dominant with a new administrative center located at Pampa Grande (Shimada, 1994b). Likely due to political infighting and environmental disasters, the Moche culture in the Lambayeque Valley Complex declined in the 800's and was later supplemented by the theocratic Sicán polity (Shimada, 1994b).

These of course are large-scale events that would have been experienced and reacted to differently based upon local ecology and culture. For instance, Ventarrón, the site on which this thesis focuses, is located next to a river and may have been impacted by flooding differently than a site located somewhere else in the Moche realm. In addition, just because large political systems declined during this time does not necessarily mean that the local political systems at Ventarrón did too. Instead, daily life could have carried on as normal despite the large-scale events happening around them. By studying the remains of individuals in local contexts, bioarchaeologists create a more nuanced understanding of not only the myriad of ways broad environmental and political changes can impact local populations, but also the variety of responses that can effectively (or not) respond to such changes. By doing so, bioarchaeologists can avoid oversimplifying universal processes of stress.

1.2 Research Questions

This thesis employs dental histological methods to analyze internal enamel micro-defects, also known as Wilson Bands, to study early-life stress and its downstream effects over the life course in human remains associated with three cultural periods in Peru's northern coastal Lambayeque Valley Complex. The study centers on three main areas of inquiry:

1. **Are markers of stress occurring within the first years of life in the Lambayeque region significantly associated with earlier age-at-death?** The Barker hypothesis or the Developmental

Origin of Health and Disease, posited that in order to survive a stress early in life, the body creates a trade-off that makes an individual frailer and more susceptible to death at an earlier age (Barker, Osmond, Golding, Kuh, & Wadsworth, 1989). Phenotypic plasticity, a modification of the Barker hypothesis, argues that the body invests energy and resources into phenotypes that promote early life survival at the expense of future growth and longevity (Temple, 2019; Worthman & Kuzara, 2005). Both hypotheses have expanded our understandings of early life stress. Previous bioarchaeological literature examining evidence of stress in bones (Temple, 2008) and teeth (Armelagos, Goodman, Harper, & Blakey, 2009; Garland, Turner, & Klaus, 2016; Lorentz et al., 2019; Lukacs & Walimbe, 1998) suggests that pre-Hispanic individuals in the Lambayeque Valley Complex should demonstrate decreased life expectancy after experiencing stress in early life.

2. **Do markers of early-life stress significantly vary between the individuals in this thesis, who are primarily associated with the Late Moche period (550-850 CE), and individuals from another Lambayeque site associated with the later Spanish Colonial periods?** Garland et al. (2016) previously reported a higher prevalence of Wilson bands at the Early Colonial (1533-1620 CE) cemetery than at the Middle/Late Colonial (1620-1760 CE) cemetery at the site of Eten, and interpreted these data as reflecting acclimation to life under Spanish oppression. This thesis aims to complement this previous study and asks: Is there a difference between the average number of Wilson bands between archaeological samples before and after Spanish colonization? Did Spanish oppression truly cause unprecedented early life stress on the indigenous populations living there, or was this frequency of early life stress common even before colonization?
3. **How can patterns of early-life stress, represented by Wilson bands in enamel, amongst the Late Moche (550-850 CE) culture be interpreted in an ecological and biocultural context?**

Specifically, how might these patterns elucidate the ways in which aspects of Moche culture mitigated or exacerbated environmental stressors? While the small sample size precludes any broad generalizations about either the region or the culture, this study aims to focus on the individuals and use them as osteobiographical case studies as opposed to population-level datasets. Osteological data from Klaus (2018a) combined with Wilson band data provide a more nuanced understanding of these people's lives.

The overall aim of these three areas of inquiry is to better understand patterns of early-life stress, their potential causes, and their downstream effects across the life course among those living in the Lambayeque Valley Complex. Chapter 2 provides an overview of stress, what it looks like in the human body, and previous bioarchaeological studies of childhood stress in the study area. Chapter 3 provides a closer examination of the interplay between culture and environment in the Central Andes. Chapter 4 explores the sociocultural history of the north coast of Peru, with a focus on the Moche. An overview of the study and the methods used are discussed in Chapter 5. Finally, Chapter 6 summarizes the results and provides interpretations of the data, concluding this study.

1.3 Significance

Today the Earth's climate is drastically changing, resulting in an increase in extreme weather patterns and a generally warmer environment. As evidenced by the COP26 climate conference ("COP26: Together for Our Planet | United Nations," n.d.), and *West Virginia vs EPA* ruling (Tollefson, 2022), we are rapidly approaching many of the worst-case scenarios projected by researchers, and will likely exceed them. The question is no longer "what can we do to avoid this catastrophe?" but rather "what can society attempt to do to adapt and survive it?"

Archaeologists, by studying the physical remains of the past, are in a position to contribute unique data to this problem. Unlike studies of the contemporary world, archaeologists can study the long-term effects of climate change on human populations (McMichael, 2012). When done holistically, these studies can provide information on not just how humans were affected biologically, but also how culture mediated (or exacerbated) their interactions with a changing environment. In areas where migration and socioeconomic changes have resulted in a loss of collective memory, archaeologists are able to recover past adaptations when this knowledge is lost to current groups (Riede & Sheets, 2020). Archaeologists also work all over the world and can provide region-specific evidence for impacts of and resilience to climatic instability (Billman & Huckleberry, 2008; McMichael, 2012).

Although it is important to study regional impacts of climate change, focusing on the Andes will provide invaluable information as the region is constantly in a state of climatic variability, facing extreme weather regularly. As the world at large prepares for (or does not) extreme, temperamental weather, studying a region already beset by such conditions can create a baseline-model for how past groups have dealt with massive floods and long-lasting droughts. In addition, by focusing on childhood stress, this study will serve as one proxy for the effectiveness of past practices. Just because archaeological evidence exists demonstrating past efforts to buffer against and utilize the environment does not mean that these efforts were effective.

In addition, this study highlights the importance of conducting research ethically. This study was planned and conducted on dental samples curated in Georgia State's Bioarchaeology Lab. While new excavations are important for expanding knowledge and testing new hypotheses, previously excavated remains can also inform research without requiring new excavations. There are currently many collections around the globe sitting on shelves that have never been studied or have been understudied (Childs, 1995). Again, while new excavations are important, I argue that it should be an ethical concern

to study and give purpose to older collections (Kersel, 2015; Voss, 2012). Why keep archaeological materials if they are never to be studied or are otherwise neglected?

Additionally, by utilizing dental samples that have already been subject to destructive isotopic analysis (Turner & Klaus, 2020), this study furthers investigative inquiry while minimizing additional destruction of finite archaeological samples. Destructive analyses mean no other research can be conducted on the material, even if better methods or additional questions arise in the future. As such, researchers need to be careful to limit how much material is destroyed. For this study in particular, an out-of-control sugar cane field fire in 2017 destroyed the archaeological and skeletal materials that had been recovered from Ventarrón (“BBC,” 2017). The only skeletal elements remaining are housed at the Bioarchaeology Lab at Georgia State University. Any additional research questions concerning the skeletal remains must be conducted here. By using material that has previously been collected and exported for analyses, this study will make the most of the remaining materials from the site.

Finally, this study serves as a comparison to a previous study on early life stress in Colonial Peru conducted by Garland et al. (2016). Garland et al. found a high prevalence of Wilson bands at the two sites studied, La Capilla Del Niño Serranito (1533-1620 CE) and La Capilla Santa María Magdalena De Eten (1620-1760 CE) and was interpreted to show acclimation to Spanish rule. However, there have been limited pre-Hispanic studies examining Wilson band formation along the north coast. If the results of this study show that Wilson band prevalence was already high in the area prior to the arrival of the Spanish, then the interpretations from that study may need to be reconsidered to account for the new context provided by this work.

2 THEORIES AND METHODS IN BIOARCHAEOLOGY

2.1 Introduction

Bioarchaeology is a subdiscipline of anthropology, bringing together archaeology and biological anthropology. Bioarchaeologists study human remains from archaeological contexts to learn more about the lives of individuals and populations from the past (Larsen, 2002). The skeleton constantly forms and remodels throughout life, reflecting life experience as it does so. Sex, age, disease, trauma, and more can all leave their mark on the bones and enamel that make up the human body and tell the story of a person's life long after they pass. It is up to bioarchaeologists to examine and interpret these remains to gain a better understanding of not just the people being studied, but how their life experiences can teach us more about the world today.

Bioarchaeological theory focuses on interpreting the interaction of biology and culture on the body. This chapter is broken into three sections and will explore some of these theories. The first section examines what stress is, how it manifests on the body, and how culture mediates its expression. It then examines limitations inherent to the study of human remains and interpreting the lives of those whom we study. It concludes with an examination of a specific limitation of bioarchaeological studies, the difference between health and stress. The second section provides an overview of what childhood stress is and how it manifests on the body. The third section examines previous studies of childhood stress along the north coast and how other researchers have interpreted their findings.

2.2 Theoretical Approaches to Stress

2.2.1 What is Stress?

Although the definition of stress has broadened over the years (Temple & Goodman, 2014), researchers generally agree that stress is a biological response to an outside stimulus that disrupts

homeostasis, or a range of “normal” conditions in which humans are primed to function (Goodman, Martin, Armelagos, & Clark, 1984, p. 15; Moran, 2008, p. 5; Temple & Goodman, 2014). Stressors usually prompt one or more biological responses, many of which manifest in soft tissues and some of which manifest in the hard tissues of the skeleton and dentition. While some contexts preserve soft tissues in archaeological human remains, most of the research examining stress in said remains focuses on lesions and other markers preserved in hard tissues. Stress may occur from constraints in the environment (including biotic and abiotic factors), cultural systems and structures, and often a combination of the two (Goodman et al., 1984; Temple & Goodman, 2014).

Environmental stressors include abiotic and biotic factors. Abiotic factors include temperature, aridity, altitude, and climatic variability. For example, the body must maintain a certain range of temperature and water content in order to function properly. The thinner air at higher altitudes decreases the amount of oxygen taken in with each breath, which can result in hypoxia. This condition, in which the tissues do not have adequate oxygen, makes physical activity harder and decreases reproductive capacity (Moran, 2008, p. 158). Climatic variability, which results in changes to the average environmental conditions, changes the environment that humans have adapted to live in. Gradual events, such as a warming or cooling environment, along with sudden events, such as a flood or volcanic eruption, are included here (Moseley & Keefer, 2008; Shepherd, 2020). Biotic factors include disease-causing microbes, biodiversity and the nutritional content in food, and competition with other organisms for resources (Moran, 2008, p. 6). Disease-causing microbes can stop the body from functioning normally and results in the body having to use valuable resources and energy to remove the invaders (Walker, Bathurst, Richman, Gjerdrum, & Andrushko, 2009). Although it varies per individual, the body needs a diverse range of proteins, fats, and macro and micronutrients in order to function (Molnar, 2005). Biodiverse environments are more likely to contain the required nutrients than an

environment with only a few organisms. Finally, competition with other organisms can result in violence and direct harm, or indirect harm through the reduction of available resources.

Culturally-derived stress also has a large impact on humans, often through its mediation of access to resources and risk exposure (DeWitte & Stojanowski, 2015). Inequality, whether based on socioeconomic standing, sex, ethnic identity, and/or other axes of identity and social positioning, can impact one's access to nutritious food, water, shelter, clothing, and more (Klaus, Harvey, et al., 2017). Inequality also mediates where one can live, often marginalizing some to unsanitary and unsafe environments. Political and economic instability, both of which are top-down forces, can be extremely disruptive to daily lives and result in a breakup of activities such as trade or farming (although see Sharratt (2020) for how local groups have exhibited resiliency against top-down forces).

Not only do cultural stressors exacerbate existing environmental stressors and vice versa, but many different stressors exist simultaneously, creating feedback loops and traversing macro- and micro-levels of societies. For example, climatic stressors that cause food insecurity, such as drought, may result in malnutrition and susceptibility to disease. Cultural stress, such as the inequality described above, acts as a filter such that marginalized groups with decreased access to resources are often unproportionally affected by climatic stressors. This in turn can lead to instability and the partial or complete dismantling of political and economic systems which can (although again, not always) exacerbate food insecurity, nutritional deficiencies and resiliency to disease (McMichael, 2012). Warfare is both a cause and result of instability. Not only does warfare redirect resources and manpower away from harvesting food and feeding the general populace, but direct violence can injure individuals, destroy crops and food sources, and force migration (DeWitte & Stojanowski, 2015; McMichael, 2012). Once refugees, people are often food insecure and at a higher risk of contracting a disease (McMichael, 2012). Traveling, whether from forced migration, trade, or other causes, can facilitate the spread of disease (Kiracofe & Marr, 2008).

Stress can manifest itself on the skeleton in many different ways, depending on the etiology of stress, the type of tissue affected, its duration, and how many simultaneous or sequential stress events are encapsulated in each lesion. As noted above, stress can result from a variety of causes. Some of these causes, such as infection with tuberculosis or leprosy, can create highly diagnostic lesions on the skeleton that allow researchers to specifically identify the disease that an individual had (Roberts, 2011). However, most forms of stress do not leave distinctive markings, and different stressors may result in the same type of non-specific lesion. Take, for instance, periostitis. Periostitis occurs from inflammation of the periosteum and most commonly appears on the long bones as a rough, bumpy patch of abnormal bone. Many stressors including infection or physical trauma may cause this reaction (Roberts & Manchester, 2005, p. 172). So, while finding a patch of periostitis means that the individual had experienced some form of stress, the exact cause is unknown.

Of course, not all stress events cause skeletal lesions (DeWitte & Stojanowski, 2015; Wood et al., 1992). Consider an individual suffering from a cancer of the soft tissues. While close proximity to a bone may cause a periosteal reaction, the pathobiology of many forms of cancer does not involve dissemination of tumor cells to bone, leaving no trace for bioarchaeologists to find. Moreover, the slow rate of formation, turnover, and alteration of bone keeps many acute stressors from leaving a lesion (Roberts & Manchester, 2005, p. 13). As such, there are many stress events that bioarchaeologists are unable to “see.”

Stressors are also defined as either acute or chronic. Acute stressors occur over a relatively short period of time and include illnesses such as diarrheal diseases, nutritional deficiencies such as that which might occur after a summer of poor harvests, and injuries (Goodman et al., 1984; Kendall, Millard, & Beaumont, 2021). Because they last for a relatively short amount of time, acute stressors do not always leave a lesion on hard tissues, which have much longer intervals of metabolic turnover. Unless it occurs during tooth formation or with chronic patterning (see below), diarrheal diseases do not typically

leave a mark on the body even though they cause a temporary nutritional deficiency. Chronic stressors, in contrast, occur over a long period of time, although they do not have to be constant. For instance, an individual who suffers from a severe vitamin D deficiency every winter is still experiencing cumulative stress even if they recover some over the summer (Goodman et al., 1984; Veselka, Hoogland, & Waters-Rist, 2015). Besides long-lasting nutritional or metabolic deficiencies, persistent diseases including tuberculosis can also be chronic (Roberts, 2011).

Related to acute and chronic stressors are episodic and cumulative stressors. Skeletal lesions produced by episodic stress events can be attributed to one time period, while lesions produced by cumulative stress events are a result of many stressors over time or a long-lasting stressor (Goodman et al., 1984, p. 15). Wilson bands, to be discussed in detail later in this chapter, are skeletal lesions that form in enamel during tooth formation (Hillson, 1996, p. 161). Because lesion formation is linked to a specific time period during the development of the tooth, Wilson band presence represents a distinct episode of stress experience and its manifestation into the body (Goodman et al., 1984, p. 27). In comparison, achieved stature is dictated by both genetics and the socioeconomic-nutritional environment (Molnar, 2005). Short stature across an archaeological sample represents the cumulation of stress throughout childhood, not one event (Goodman et al., 1984, p. 19). Due to the constant remodeling of bone throughout life and cessation of growth after childhood, most lesions are cumulative but not necessarily permanent. And since cumulative lesions are a result of many stressors or a chronic stressor, the occurrence of a singular acute stress event is easily obscured.

Of course, humans are not hapless creatures at the mercy of every potential stressor around them. Humans respond to stress both biologically and culturally. Briefly, there are three major types of biological responses: evolutionary adaptations; developmental adjustments; and acclimatory/regulatory adjustments. Evolutionary adaptations result in a change of gene frequencies in a population and include adaptations such as melanin content in skin, which came about as a balancing act between UV

protection and vitamin D absorption (Jablonski, 2013, p. 61; Moran, 2008, p.9). Developmental adjustments occur in childhood in response to the environment and are not reversible, nor can they be developed later in life by adults (Moran, 2008, p. 9). For instance, a child growing up in a high-altitude environment will develop increased lung capacity, which increases the amount of oxygen they can take in with each breath (Moran, 2008, p. 166). Finally, adjustments occur in response to a changed environment and are reversible (Moran, 2008, p. 9). Acclimatory examples include changing blood pressure depending on altitude (Moran, 2008, p. 165).

Culture, besides being a potential source of stress, acts as a regulatory mechanism. Take for instance the custom of washing one's hands after using the restroom or before eating. This practice helps to remove germs and keeps people from getting sick. Cultural adjustments are an extremely important response to stress as they are (hypothetically) rapidly changeable and reflect generations of accumulated and transmitted knowledge (Goodman et al., 1984). Humans evolved plasticity, which allows them to survive and conform to a multitude of changing environments. As such, most of humanity's responses to stress involve either developmental or acclimatory/regulatory adjustments, not evolutionary adaptations (Moran, 2008, p. 9).

Stress that occurs early in childhood is important due to the potential effects it has later in life. The Barker hypothesis, also known today as the Developmental Origins of Health and Disease states that surviving early life stress, especially stress in utero or as an infant, causes disease and early mortality later in life (Barker et al., 1989; Gillman, 2005). This trade-off suggests that survival of stress comes at a cost. Low birth weight and intrauterine deficiencies have been extensively studied in living populations and linked to diseases later in life, including diabetes and cardiovascular disease (McMillen & Robinson, 2005). Phenotypic plasticity, which can be understood as a modification to the Barker hypothesis, has been defined as "the ability of individual genotypes to produce different phenotypes when exposed to different environmental conditions" (Fusco & Minelli, 2010, p. 548). In other words, when faced with an

early life stress event, the body intentionally invests in phenotypes that promote short-term survival by reallocating energy and resources away from biological processes that would support a longer life.

Conversely, in environments without early life stress events, the body invests resources and energy into phenotypes that promote long-term growth and reproduction. Although phenotypic plasticity and the Barker hypothesis can be used to understand how a single type of stress event impacts mortality, they also allow researchers to consider different combinations of acute, chronic, episodic and cumulative stress as they relate to and exacerbate each other over the life course.

Recently, the Barker hypothesis has been utilized by bioarchaeologists to try and explain early mortality in correlation to skeletal stress lesions. Armelagos et al. (2009) used a review of linear enamel hypoplasias and hypocalcified enamel to examine mortality in archaeological samples. The authors concluded that enamel lesions represent either 1) individuals who were frail prior to experiencing a stressor, and as a result of this pre-existing frailty developed an enamel lesion and died early; 2) individuals with continued differential exposure to stress throughout their lives, such that individuals living in poverty were more likely to not only develop a lesion, but die earlier as a result of continued poverty; or 3) individuals who, because they had undergone a stress event that resulted in an enamel lesion, were unable to respond to future stress events and thus died earlier. Garland (2014) used Wilson bands and linear enamel hypoplasias to examine early life stress in an Early (1533-1610 CE) and Middle/Late (1625-1760 CE) Colonial sample from Lambayeque, Peru. The author found that those with at least one Wilson band died, on average, earlier than those without any Wilson bands. In contrast, individuals with enamel hypoplasias died later than those without, seemingly contradicting the Barker hypothesis. However, Garland explained this contradiction as an example of hidden heterogeneity, to be explained later, whereby a pre-existing frailty in individuals caused them to die before an enamel hypoplasia could form. Temple (2008) examined the relationship of enamel hypoplasias to adult stature in the Jomon people from eastern and western Japan. The author concluded that, while enamel

hypoplasias provide evidence for systemic stress, their presence does not predict phenotypic variation later in life.

2.2.2 *Limitations in Bioarchaeological Studies*

There are two major biases that exist when studying skeletal remains, those associated with the Osteological Paradox and those associated with the burials and excavations themselves. The Osteological Paradox is a concept introduced in a key article by Wood et al. (1992) that calls for bioarchaeologists to critically consider biases inherent to skeletal samples when making interpretations. The three major biases making up the paradox are 1) demographic nonstationarity; 2) selective mortality; and 3) hidden heterogeneity in frailty.

Demographic nonstationarity refers to populations that are experiencing changing fertility levels and/or migration. As life history tables, which had been commonly used to assess mortality risks and age structure at sites, are reliant upon a population being stationary, demographic nonstationarity skews data derived from them. The migration of adults into a population and decreased fertility will both result in overestimations of the life expectancy of those who were buried there, just as the opposite is conversely true (Jackes, 2011; Wood et al., 1992). In addition, migrants may have both experienced different stressors in their original environment and may have different access to resources than the locals at a site (Turner & Armelagos, 2012). Treating a given archaeological sample as a stationary population may mask the different lived realities of a mixed population. In recent years, this bias has been addressed through the use of numerous models and heavy isotopic analyses to identify migrants (reviewed in DeWitte & Stojanowski, 2015).

Selective mortality refers to how within a living population, every age group has a certain risk of disease or death, with only a portion of those individuals dying and the rest surviving to a later age. However, in the archaeological record, everyone that we study is the portion that succumbed, i.e. the non-survivors of an age group. Excepting skeletal samples from disaster contexts, such as those at

Herculaneum (Martyn et al., 2020) or Hasanlu (Toebbe, 2005), archaeological populations cannot be considered *a priori* as representing the living population, and skeletal lesions are expected to be overestimated for each age group, particularly amongst young adults and subadults (Wood et al., 1992).

Hidden heterogeneity in frailty centers on the fact that individuals in a population vary in their risk of morbidity and mortality from the same stressor, due to a variety of factors including but not limited to genetic immunity or susceptibility to disease, actual exposure to disease, and existing health status such as nutritional status or infection burden. All of these factors are influenced by socioeconomic standing, sex, cultural affinity, and other axes of identity and social positioning. This difference in risk results in a heterogeneous population with different risks of dying and different degrees of endurance in the face of a given stressor. Examining aggregate patterns in the archaeological record can mask the heterogeneity in the population, thus making it difficult to assess an individual's or subgroup's risk of dying. And while some causes of heterogeneity can be factored into analyses, such as testosterone acting as a suppressant to immune response, many other causes remain unknown, leading to hidden heterogeneity (DeWitte & Stojanowski, 2015; Wood et al., 1992). In order to best avoid this pitfall, Wood et al. (1992) suggests that researchers not only understand the context of the site they are studying, but to also focus on simple sites with short usages and one cultural and egalitarian group.

Wood et al. (1992) also highlighted the difficulty in interpreting the presence and absence of stress lesions. Having a stress lesion means that an individual experienced a stress incident and lived long enough for the lesion to form. While the absence of any stress markers could mean that the individual never experienced any stressors, it could also be that the individual either died from the stress before it had a chance to form a lesion or died from a stressor that does not leave a skeletal lesion. Therefore, are individuals with stress lesions actually better off than their unblemished counterparts? This problem of interpretation brings into question the relationship between health and stress, which is discussed in more detail later in this chapter. However, for now it should just be noted

that these concerns over interpretation again beg the importance of basing interpretations in the context from which they originate.

Biases associated with interments and excavations include factors such as the composition of the funerary site. Did the population inter children separately from adults? Were soldiers, pilgrims, and other migrants brought home for mortuary treatment, or laid to rest far away? Were migrants, merchants, or others passing through given similar mortuary treatment to local community members (Jackes, 2011)? Questions such as these require us to understand the context in which the population was interred to determine if the site contains more or fewer individuals than those who lived at the site. Biases also occur based upon what is being excavated and what remains to be excavated.

Bioarchaeologists might not be able to fully excavate a burial site for numerous reasons including if part of the site was looted, if construction has destroyed or made part of the site inaccessible, environmental changes such as rising sea levels or changing river paths, laws forbidding archaeologists from accessing certain lands, or even just failure to locate the entirety of the site (Jackes, 2011). Even with full access to the site, an archaeologist may decide to not excavate or only excavate a limited section for ethical reasons (Balanzátegui Moreno, 2018). In addition, the deterioration of bone via a host of taphonomic processes, which particularly affect subadult remains, can completely erase their presence from the record or obliterate important skeletal markers for stress, sex, and age (DeWitte & Stojanowski, 2015; Jackes, 2011).

2.2.3 *Health and Stress*

Although sometimes used interchangeably by researchers (see for instance Pietrusewsky et al., 2016; Wittwer-Backofen & Tomo, 2008), health and stress are distinct but related topics in the field of bioarchaeology. At its core, stress is a biological response and as such can be measured and studied in human bodies (Temple & Goodman, 2014). In contrast, health is a holistic and abstract term that varies

per person (DeWitte & Stojanowski, 2015). While the WHO defined health in 1948 as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity,” others have fought against the vagueness and use of the term “complete,” arguing that health is determined by the individual and cannot be quantified by an outside agency (Jadad & O’Grady, 2008). Put otherwise, individuals have their own nuanced definitions of health that may change over time, and only they know where they stand in regard to their own definition. Thus, health is subjective and what an individual might consider healthy can be considered unhealthy by researchers or other institutions. While a researcher today can try to understand health by asking an individual about their personal health views, a bioarchaeologist should be very concerned to receive answer.

While stress does play an important role in health (for instance, someone infected and dying from COVID is unlikely to be considered healthy), health also encompasses mental and social well-being (DeWitte & Stojanowski, 2015; Temple & Goodman, 2014). Because bioarchaeologists cannot speak to the dead and very few individuals in the past have left written records regarding their thoughts, it is all but impossible to understand what the mental and social state of those being studied were. Bioarchaeologists can study and understand stress through the skeletal lesions it leaves, but stress does not serve as a proxy for mental or social health. So, even though bioarchaeologists can examine one important factor in health, they are unable to learn much about the other factors. Since health can only be understood by examining all factors together, bioarchaeologists cannot make any definitive statements on health.

To complicate matters of health and stress further, culture significantly moderates people’s perceptions of stress and must be considered before making any assumptions of health and stress (DeWitte & Stojanowski, 2015; Goodman et al., 1984; Reitsema & McIlvaine, 2014; Temple & Goodman, 2014; Wood et al., 1992). For instance, not all biological stressors are considered unhealthy by different people and cultures (Reitsema & McIlvaine, 2014; Temple & Goodman, 2014). Consider the rising

prevalence of vegan diets. Eating vegan is promoted as a healthy and green alternative to animal-based diets. And while it can be green, many individuals eating vegan diets do not consume adequate amounts of B12, resulting in a deficiency which can be especially problematic during pregnancy (Franssen, Maroske, & Langlitz, 2017). Relatedly, what does stress and health have to do with how one lives their life (Reitsema & McIlvaine, 2014)? For many, biological stressors, even those considered unhealthy by themselves and their culture, are only a small part in their lives. For example, if asked to describe their life, a person with Type I diabetes would likely spend more time discussing their job, friends, and family than they would their diabetes and its impact on their life. One can only imagine that past populations would be the same.

2.3 The Skeletal Manifestation of Childhood Stress

2.3.1 Dental Stress Markers

Dentition has many unique characteristics that make it extremely valuable to study. In living individuals, teeth are exposed to and impacted by the outside world on a daily basis, whereas skeletal elements are not (Hillson, 1996, p. 1). Unlike skeletal elements, the enamel of the crown of the tooth is not composed of cells but rather a mineral matrix. As a result, dentition preserves well in the archaeological record even in instances where the skeleton does not (Hillson, 1996, p. 181). The mineral composition of enamel cannot be modified after its formation and maturation, meaning that any lesion that occurs during formation remains there for the course of an individual's life unless removed by dental wear (Hillson, 1996, p. 148). Since enamel forms over the course of gestation and childhood, any stress lesions identified in enamel can be linked back to an episodic stress event in childhood. As such, the study of stress lesions in the crowns of teeth is an important tool for minimizing the osteological paradox as evidence of childhood stress can be studied in the survivors (Armstrong et al., 2009; Garland et al., 2016; Temple, 2019).

The most commonly studied stress lesions in enamel include linear enamel hypoplasias (LEH) and Wilson bands (FitzGerald & Saunders, 2005; Goodman & Rose, 1990; Hillson & Bond, 1997). Both enamel hypoplasias and Wilson bands result from a disruption in the circadian deposition of enamel caused by a non-specific stressor (FitzGerald & Saunders, 2005; Goodman & Rose, 1991; Hillson, 2014). Enamel hypoplasias form on the exterior surface of the enamel and typically appear as a depressed, horizontal band (Hillson & Bond, 1997). Wilson bands occur on the interior of the enamel and have been described as accentuated striae of Retzius (FitzGerald & Saunders, 2005). They must be studied utilizing a polarizing light microscope. Both lesions will be discussed in more detail below.

The formation of teeth intersects with the creation and analysis of stress lesions. Both deciduous and permanent teeth form in the same process and have a dentine center surrounded by an enamel crown exterior; both are joined to a cementum root. The development of teeth is staggered, beginning with the formation of deciduous incisors around four months *in utero* and ending with the formation of the crowns of third molars around twelve to sixteen years (Hillson, 1996, p. 123). Enamel begins as a mixed organic and mineral matrix deposited by an epithelium sheet composed of ameloblast cells (Goodman & Rose, 1991, p. 280; Hillson, 1996, p. 148). This deposition occurs in layers that are deposited daily (FitzGerald, 1998). Apatite crystallites are seeded into the matrix, where they continue to grow. After secreting the matrix, ameloblasts begin breaking down most of the organic portion of the enamel, primarily leaving the mineral portion (Hillson, 1996, p. 149). Enamel deposition begins at the dentin-enamel junction and continues to the surface of the tooth. The first layers are small, dome-like structures situated where the future cusp(s) will be, on top of the dentine horns (Hillson, 1996, p. 119, 2014, p. 31). Successive layers increase the size of the dome(s) until the occlusal surface is complete. Next, successive layers begin forming down the sides of the tooth until they reach the cervix (Hillson, 1996, p. 120).

This circadian layering of enamel results in unique microstructures within the tooth, which can be viewed with a polarized light microscope. Prism rods are the basic unit of enamel and are viewed as alternating light and dark bands running from the dentin-enamel junction to the surface at about 120 degrees (Hillson, 1996, p. 153). Hunter-Schreger bands represent undulations in the prism rods and can be seen by the naked eye as light and dark bands within the tooth (Hillson, 1996, p. 153). Perpendicular to the prism rods are the cross striations, which represent the daily deposition of enamel. The striae of Retzius are similar to the cross striations; however, these occur on average every 8-9 days (McFarlane, Littleton, & Floyd, 2014). At the end of each 8-9 day cycle, the deposition of enamel matrix slows down resulting in a discontinuity in the matrix that causes light to scatter when viewed under a polarized light microscope. Cross striations and striae of Retzius are closer together and more poorly defined near the dentin-enamel junction, become clearer and further apart towards the surface of the tooth, and again become closer together and poorly defined near the cervix as a result of the slowing of enamel deposition (Hillson, 1996, p. 155). Finally, perikymata form where striae of Retzius reach the surface of the tooth, resulting in a wave-like pattern (Hillson, 1996, p. 163). Because they result from striae of Retzius, perikymata follow a similar pattern of being more spaced out near the occlusal surface of a tooth and closer together near the tooth cervix (FitzGerald & Saunders, 2005; Hillson, 2014, p.167).

Wilson bands, also known as accentuated or pathological striae of Retzius, can occur when an individual experiences non-systemic or acute stress. The normal cessation in enamel deposition is elongated due to metabolic disruption, resulting in a broad band of atypical prism alignments that scatter the light differently under a polarized light microscope. To the viewer, these atypical alignments appear as visibly exaggerated striae of Retzius (FitzGerald & Saunders, 2005; Hillson, 1996, p. 160). The neonatal line is a special type of Wilson band and occurs from the stress of being born (Hillson, 1996, p. 159). Only teeth with enamel forming during birth, namely the deciduous and permanent first molars, will exhibit the neonatal line (FitzGerald & Saunders, 2005). As a result of the regular deposition of

enamel, striae of Retzius can be counted from the neonatal line to another Wilson band, and the age at which the stressor occurred can be estimated (FitzGerald, Saunders, Bondioli, & Macchiarelli, 2006).

FitzGerald and Saunders (2005) note that past research has found links between neonatal asphyxia, intrauterine undernutrition, maternal diabetes, birth weight, and minimal brain dysfunction and related neurological disorders. However, most research has focused on the impact of poor nutrition and disease on Wilson band formation, with the general consensus being that short term bouts of illness, especially those that lead to a rapid depletion of nutrients, cause a prolonged cessation of ameloblast activity (Hillson, 1996; Katzenberg, Herring, & Saunders, 1996; Marks, Rose, & Davenport, 1996; Simpson, 1999). Wright (1990) further argues that only severe stress events will result in the formation of a Wilson band, while FitzGerald and Saunders (2005) argue that any stress will result in a Wilson band, but only those that occur during the natural cessation of enamel deposition will leave a mark.

Simpson (1999) explores the link between weaning and Wilson band formation. Weaning is typically broken into two phases: complementary feeding and the cessation of breast feeding (Kendall et al., 2021). During complementary feeding, the introduction of bacteria from contaminated water sources can cause diarrheal illness in children (Katzenberg et al., 1996). The use of inferior (especially those that inhibit iron absorption) and monotonous weaning foods lacking in vitamins and other nutrients can weaken the child's immune system further, making them even more susceptible to diarrheal diseases (Kendall et al., 2021). During a bout of diarrhea, children become dehydrated and water is not utilized by the body for superfluous activities such as tooth formation, resulting in Wilson bands (Simpson, 1999).

Other factors have been argued to increase one's susceptibility to stress and subsequent Wilson band formation. Children with autism are more likely to have Wilson bands, likely a result of immune dysfunction and elevated stress (and thus cortisol) levels (Kurek, Borowska, Lubowiedzka-Gontarek,

Rosset, & Zadzinska, 2020). Biological sex has also been found to impact one's susceptibility to stress and lesion formation. Although more research is needed, Gamble, Boldsen, & Hoppa (2017) discovered that biological males with Wilson bands were more likely to die earlier while biological females with Wilson bands were actually more likely to survive longer, suggesting that females are better buffered against stress as children than their male counterparts. A similar study utilizing different stress markers came to similar conclusions (DeWitte, 2010).

Enamel hypoplasias can appear as either pits, furrows, or large troughs on a tooth. They can be caused by genetics, trauma, or non-systemic stress. Typically, hypoplasias caused by genetics tend to be severe and impact the entire tooth crown while enamel hypoplasias caused by trauma are isolated to one tooth or a few adjacent teeth (Goodman & Rose, 1991). Both are exceedingly rare in the archaeological record and will not be discussed further. Enamel hypoplasias resulting from systemic stress appear as a depressed band on the surface of the tooth. Hypoplasias are most common in the middle and cervical two-thirds of anterior teeth (Goodman & Armelagos, 1985). It is tempting to create an association between the breadth of the hypoplasia and the severity of the stress that caused it; however, the size of the hypoplasia is related more to its placement on the tooth than the severity of the stressor (FitzGerald & Saunders, 2005). Because enamel deposition slows as it reaches the cervical margin of the tooth, perikymata are further apart towards the occlusal surface and closer towards the tooth cervix. A hypoplasia encompassing the same number of perikymata would differ in size depending on where it was located. In addition, associated hypoplasias located on different teeth have been found to encompass different numbers of perikymata (Hillson, 2014, p. 167).

Overall, most bioarchaeologists concur that Wilson bands and LEHs have separate etiologies, with Wilson bands forming from short-term stressors (1-5 days) such as gastrointestinal diseases (Simpson, 1999) and LEHs forming from longer-term stressors (semi-acute to more chronic) such as undernutrition (Goodman, Martinez, & Chavez, 1991). As such, Wilson bands are a more sensitive and

finite indicator of stress. Wright (1990) found no association between Wilson bands and LEH, further supporting this theory. Although Simpson (1999) notes that Wilson bands are often associated with the onset of a LEH, they attribute this to an overlap in causes with many chronic diseases beginning with short-term stressors such as vomiting or diarrhea.

2.3.2 Skeletal Stress Markers

Like teeth, the skeleton can also be impacted by and embody childhood stress. Unlike teeth, the skeleton continues to remodel throughout life, which can result in the eventual erasure of childhood stress lesions later in life. In addition, unlike dental development, skeletal growth and development is not as highly canalized. As a result, the age at which a stress event occurs cannot often be pinpointed. Although there are many ways to examine childhood stress, only terminal stature, rickets, scurvy, cribra orbitalia, and porotic hyperostosis will be discussed here.

Terminal adult stature has been primarily used to investigate nutritional deficiencies and to a lesser extent disease and labor expenditure in childhood. Terminal stature is dependent upon both genetic and environmental factors such that one's genetic potential height can only be reached in an environmentally favorable context (Goodman et al., 1984; Molnar, 2005; Roberts & Manchester, 2005). As such, stature represents a potential cumulative record of non-specific and chronic stress events. The most common of these stress events is a nutrient-depleted diet and high, constant disease exposure, which will result in stagnated growth in children (Bogin, Wall, & Macvean, 1992; Molnar, 2005, p. 227; Stinson, 1982). In archaeological samples, long bones (and especially femora that are used as a proxy for height) will measure shorter than expected. Because dental development is highly canalized and reflects chronological age, tooth chronology can be compared to stature and standardized growth curves to study nutritional deficiencies in the remains of children. As children get older, those who had previously experienced a stagnation in growth may go through catch-up growth in their late teens (Molnar, 2005,

p. 229). Adult stature then may be a result of normal growth throughout childhood or later catch-up growth, making it difficult to determine who might have been stressed in childhood. Instead, the mean height of large adult samples can be gathered and compared to other mean heights across time to determine if stature (and likely access to nutrition/disease exposure) changed (Goodman et al., 1984; Roberts & Manchester, 2005).

Skeletal signs of rickets, scurvy, and anemias reflect specific nutrient deficiencies, though in the case of anemia, there are other potential causes including chronic parasite infection and inherited blood disorders. Deficiencies refer to a lack of a necessary nutrient needed for normal growth, development, and maintenance. For instance, rickets manifests in the bowing of the long bones and shorter stature in children and is caused by a vitamin D deficiency. Vitamin D can either be consumed in one's diet or created in the skin utilizing the sun (Brickley, Moffat, & Watamaniuk, 2014). Rickets result from a vitamin D deficiency caused by a poor diet or cultural practices that limit exposure to solar ultraviolet ray exposure. Deficiencies in consumed vitamin D can originate from low levels in breastmilk, weaning foods, early childhood diets, and economic activities (Brickley, Mays, & Ives, 2007; Giuffra et al., 2015; Lockau et al., 2019; Newman & Gowland, 2017; Veselka et al., 2015). Cultural practices such as restrictive clothing, avoidance of sunlight, or living in areas with long winter nights can also cause vitamin D deficiencies and rickets in children (Brickley et al., 2007; Giuffra et al., 2015; Lockau et al., 2019; Mays, Brickley, & Ives, 2009; Peacock et al., 2019; Tschinkel & Gowland, 2020; Veselka et al., 2015).

Scurvy is the product of a deficiency in vitamin C. Vitamin C is commonly found in fresh fruits and vegetables, but can also be obtained by eating raw meats and marine fish (Roberts & Manchester, 2005, p. 234). Historically, long-term storage and the lack of various fresh produce in some agricultural societies has resulted in a high prevalence of scurvy (Brickley & Ives, 2006; Roberts & Manchester, 2005, p. 234). Long sea voyages and winters may limit the amount of fresh produce consumed and may also

result in scurvy (Maat, 2004). Not only is vitamin C necessary for iron absorption, the lack of which can result in anemia (discussed below), but deficiency can also result in hemorrhaging into soft tissues, bones, and joints, especially those associated with the jaw (Roberts & Manchester, 2005, p. 235). On skeletal remains, scurvy may be identified by increased porosity on the sphenoid bone, around the alveolar sockets, and the scapula (although see Brickley & Ives (2006) and Ortner Butler, Cafarella, & Milligan (2001) for a more extensive list of scurvy manifestations on the skeleton).

Cribra orbitalia can be identified in the archaeological record as an abnormal porous lesion in the superior orbits, while porotic hyperostosis is identified by abnormal cranial vault porosity. Both are the result of chronic anemias. Broadly, anemia is caused by either a deficit of red blood cells or damaged/malformed red blood cells, which results in decreased oxygen being carried throughout the body and hypoxia (Roberts & Manchester, 2005). Red marrow spaces, which are partially based in the cranial vault in children, expand to increase red blood cell counts and can essentially leak through the cortical surface of the cranium, creating porous lesions (Klaus, 2020). In adults, red marrow shifts to the vertebrae, sternum, and coastal regions of the skeleton where the expansion of red marrow does not cause cortical bone damage (Brickley, 2018).

There are many different types of anemia. Hemolytic (in which red blood cells are destroyed faster than they can be created) and megaloblastic anemias (in which red blood cells are misshapen and do not work properly, and of which vitamin B₉ and B₁₂ anemia is included), have in recent years been argued to cause porotic hyperostosis (Walker et al., 2009). Others argue that iron deficiency should continue to be included as a potential cause (McIlvaine, 2015). A broad range of factors may cause these anemias, including diets deficient in vitamins B₉, B₁₂, C, or iron, in addition to various infections that may actively destroy red blood cells (such as leishmaniasis or bartonellosis) or may inhibit the body from utilizing various nutrients to produce healthy red blood cells (Brickley, 2018; Hotez et al., 2012; Klaus, 2020; O'Donnell, Hill, Anderson, & Edgar, 2020; Walker et al., 2009). For instance, links between

poverty, poor sanitation, vitamin deficiency, and megaloblastic anemia has been made (Walker et al., 2009), as well as respiratory illnesses and iron deficiency anemia (O'Donnell et al., 2020).

In recent years, different etiologies for porotic hyperostosis and cribra orbitalia have been suggested, in part due to the expected timing and appearance of the lesions on the cranium should they share an etiology (Brickley, 2018). It has recently been suggested that aplastic anemias, in which bone marrow cannot produce enough red blood cells, chronic diseases, and renal failure cause cribra orbitalia (Rivera & Mirazón Lahr, 2017). Differences between cribra orbitalia and lesions caused by scurvy are explored in Klaus, (2017).

2.4 *Bioarchaeological Studies of Childhood Stress Along the North Coast of Peru*

The study of human remains along the north coast of Peru is a relatively new area of research, with studies originally focusing on case studies and occasionally, when sample size allowed, population studies (Verano, 1997b, 1997a). The study of children, including childhood stress, was hindered by the looting of funerary sites, the tendency for children's remains to be more damaged during looting due to their inherent frailty, and the general underrepresentation of child graves along the north coast (Klaus, 2018b; Verano, 1997b). Despite these challenges, in recent years scholars have been publishing studies focusing on childhood stress in earnest (Klaus, 2018b). The research that has been conducted sheds a fascinating window into the early childhood of those who have called the north coast home. Anemia has been a common focus of research. In pre-Hispanic populations, porotic hyperostosis remained relatively stable from 550 CE to the arrival of the Spanish and impacted more than 40% of the remains sampled (Klaus, 2018b). Rates of porotic hyperostosis increased under Spanish rule. The same study found that rates of cribra orbitalia also remained stable over time but increased prior to the Spanish under foreign Chimú and Inka rule (1375-1532). Populations in the Colonial era had various rates of cribra orbitalia depending on the site from where they originated. A closer analysis of these two stress lesions points to

differences based on socioeconomic standing, suggesting that exposure to and the ability to buffer against childhood stress was mediated by resource access based on social standing (Klaus, 2018b; Klaus, Shimada, et al., 2017; Shimada et al., 2004). Differences in anemia based on biological sex does not appear to exist, although those living along the coast were more likely to survive having anemia than their highland counterparts (Blom et al., 2005).

What caused these markers of anemia is still being debated. A combination of insufficient vitamins such as B₉ and B₁₂, gastrointestinal infection, and parasites has been put forth as one answer (Klaus, 2018b). However, Blom et al. (2005) argues that a diet combining maize and marine protein buffered coastal populations against anemia and that instead, the high prevalence of parasites and diseases along the coast caused most anemia there. Similarly, Shimada et al. (2004) point to poor sanitation and close living quarters as a primary driver of anemia, at least for those in lower socioeconomic strata.

Prior to the arrival of the Spanish, crude prevalence of enamel lesions were relatively high with almost a third of individuals across the Lambayeque Valley Complex exhibiting at least one enamel hypoplasia (Klaus, 2018b). Although this number seems high, it suggests that most children were already experiencing a chronic stress that was survivable. In contrast, Colonial era children had lower rates of enamel hypoplasias, suggesting that they died before a lesion could form (Garland, 2014; Klaus, 2018b). The timing of enamel hypoplasia formation remained the same across the sampled population at approximately 2.2 years, likely a result of a weaning practice (Klaus, Temple, Bauer, & Merchant, 2015). If most mothers begin supplemental weaning around 6 months of age, then the formation of an enamel hypoplasia around two years of age may suggest a chronic stress associated with the cessation of weaning, such as loss of passive immunity or a new childhood diet containing fewer nutrients than breastmilk (Kendall et al., 2021). Conversely, Garland et al. (2016) found that in Colonial sample

populations, Wilson bands tended to aggregate around 4-5 months, which may point to the beginning of supplemental feeding when acute stressors such as diarrhea from contaminated water may occur.

Garland et al. (2016) also found that Wilson band prevalence decreased from the beginning of the Colonial period to the end (1532-1760), which points to the resiliency of children under Spanish rule. Unlike enamel hypoplasias, those with Wilson bands were more likely to perish before reaching the age of 12. Although no pre-Colonial individuals were included in Garland et al.'s study, the results indicate that the stressors that cause Wilson band formation were more likely to cause early mortality than the stressors that cause enamel hypoplasias.

Terminal adult stature in the Lambayeque Valley Complex is very canalized, with few sampled populations before or after Spanish conquest exhibiting stunted stature (Klaus, 2018b). However, in a Colonial sample there is evidence of subadult growth faltering (Klaus & Tam, 2009). Only those experiencing a severe stress before the age of 2 seem to experience any tradeoffs in stature later in life (Klaus, 2018b; Klaus, Shimada, et al., 2017). Other evidence of childhood stress such as rickets or scurvy is non-existent or minimal (Klaus, 2018b). Previous archaeological studies then indicate that pre-Hispanic childhood was still stressful, especially in terms of diseases and nutritional deficiencies that cause anemia or that may occur during the cessation of weaning. However, overall children were relatively buffered from the environment and were able to overcome incidents of stress.

As covered in this chapter, skeletal lesions are a physical embodiment of stress that typically result from an imbalance in nutrients, disease, or trauma. Since access to nutrients and exposure to disease is mediated by culture, lesions represent societal inequities and violence as well as diet or bacteria load. Stress that occurs in childhood results in unique skeletal lesions which often carry on into adulthood. Some of these, such as enamel microdefects, can be linked to a specific stress event. Unfortunately, identifying the exact cause of childhood stressors remains outside of the purview of bioarchaeologists today. Along the north coast of Peru, the study of childhood stress is a relatively new

field; however, existing studies are pointing to a population more affected by disease than nutrient deficiencies, with slight differences across time and socioeconomic classes.

By utilizing Wilson bands, I address two of the three issues raised by Wood et al. (1992) in this study. As detailed in the section regarding selective mortality, bioarchaeologists are only able to study those who died, and as such, lesions are overestimated. Because Wilson bands represent a survived episodic stress event from childhood, I am able to discuss early-life stress patterns in those who survived at least through infancy, if not longer. In addition, in this study I examine how individuals experiencing stress early in life are beset with frailty, which results in differential risk of mortality later in life. Although non-specific stressors cause Wilson band formation, I situate my interpretations in the place and time that these individuals lived in. Namely, I examine potential stressors caused by the physical and sociocultural environment of the north coast of Peru and their role in creating frailty within those who lived there.

3 HUMAN INTERACTION WITH THE ANDEAN ENVIRONMENT

3.1 Introduction

As noted in Chapter 2, humans have a tremendous amount of agency in utilizing culture to shape the physical environment and buffer against stress. Rarely are humans explicitly at the mercy of the outside world. Even during times of severe climatic upheaval, humanity's ability to think and adapt has allowed people to not only survive, but to thrive in even the most difficult of times. Of course, culture also creates systems and structures that mediate access to resources and expose some or all of a given population to new or worsened stressors. Perceived differences in sex, age, ethnicity, and more influences the work one undertakes, the foods they eat, where they live, and what diseases they are exposed to. As a result, artificial shortages in resources and misguided cultural practices generate their own stressors.

This chapter takes a closer look at human-environmental interactions along the north coast of Andean South America. First, an overview of the geography and resources available in the region are provided. As adaptable as humans are to the environment, they are still restricted by what is and is not there. This chapter then examines the ways that north coast populations have adapted to their environment, using the resources available to thrive in an otherwise harsh environment. In some cases, these cultural adaptations created new stressors to be endured and overcome by those living there.

3.2 North Coast Geography

The Andes are a long mountain range, spanning 7000 km from Venezuela, down the length of Ecuador, Peru, Bolivia, Chile and into Argentina. Over the past 50 million years, the Nasca and Antarctic plates have subducted under the South American plate, actively causing the sea floor to crumple and rise. The Andes consist of three main regions, including the Northern Andes, the Central Andes, and the Southern Andes. The Central Andes encompasses Peru and most of Bolivia, and portions of southern

Ecuador and northern Chile, and can be divided broadly into three environments, including a desert coastline along the Pacific Ocean, highland sierra, and tropical jungle on the eastern flanks of the mountains. The north coast of Peru consists of approximately 400 linear kilometers of desert coastline with the Sechura desert in the north and the Casma drainage to the south. In total, fourteen river valleys punctuate the desert, flowing westward down the Andean slopes towards the Pacific. The Lambayeque Valley Complex is located in the northern north coast. Unlike the southern portion of the north coast, the foothills of the northern north coast are lower and located further inland, the mountain slopes are less steep, and the mountain ridges surrounding the river valleys are less severe (Shimada, 1994, 41). This is especially true of the Lambayeque River Valley Complex, where five river valleys blend seamlessly with one another (Turner & Klaus, 2020, 35). These individual river valleys include the Motupe, La Leche, Lambayeque, Reque, and Zaña.

The desert environment along the north coast is ironically caused by its proximity to the ocean. The Humboldt current originates in the icy waters of Antarctica and flows northward along the coast of South America. It not only displaces warmer waters to the west, but also cools the surrounding ocean air masses (Johnson, 1976). When this cool air passes over the warm land, its capacity for moisture retention increases until it is pushed east and onto the mountains, where precipitation can only occur around 1500 masl (Johnson, 1976). Because it receives very little rain, most of the liquid water present along the north coast comes from either glacial runoff or runoff from rains above the 1500 masl mark (Shimada, 1994, 37). Another source of moisture comes from the cold, moisture-rich air flowing from the ocean towards the landmass. When trapped under warm air, the dense fog in the cooler air supports patches of fog-dependent plants, known as *lomas* (Beresford-Jones et al., 2015; Caramanica, Quilter, Huaman, Villanueva, & Morales, 2018). These are not constant water sources and fluctuations are common, as to be discussed below.

The cooler Humboldt current not only creates the desert along the coast, but also provides the region with diverse marine resources. The surface waters above the Humboldt current are sheared off by the prevailing southerly winds, allowing cold water with low dissolved oxygen and high nitrogen and phosphorous concentrations to rise to the surface. This phenomenon, known as an “Ekman Spiral,” creates an upwelling environment that is ideal for phytoplankton and supports a large marine ecosystem (Cane, 1986). The Humboldt current also flows slowly, which creates stable temperatures similar to those in the open ocean and supports large quantities of marine life. The end result is one of, if not the, richest fisheries in the world replete in clams, mussels, crustaceans, anchovies, sea lions, whales and dolphins, sea birds and waterfowl (and their *guano*, or nutrient-rich excrement), seaweed, and a staggering variety of fish species (Reitz, Andrus, & Sandweiss, 2008).

Resources come not just from the ocean, but from the land as well. The north coast river valleys contain many microenvironments that support a diverse array of resources. The Lambayeque Valley Complex is especially representative of these microenvironments. The littoral zone borders the ocean and land. This zone can be narrow and rocky or wide and sandy. The major resource extracted from the littoral zone includes marine life and salt (Shimada, 1976, 28; Turner & Klaus, 2020, 36). The coastal deserts east of the littoral zone surround the river valleys and contain both active and semi-stabilized sand dunes. Other than a few shrubs and grasses, little grows here unless there is excess water to saturate the fields. Next is the *monte* zone, which contains a variety of scrubby trees including the *algarrobo* tree. The *algarrobo* tree produces a sweet fruit that can be fermented into an alcoholic beverage, and the tree itself is used for foddering, fuel and construction (Turner & Klaus, 2020, 36-37). Riverine zones exist along rivers and irrigation canals and consist of rich alluvial floodplains (Shimada, 1976, 36; Turner & Klaus, 2020, 37). This zone supplies building materials such as cane, sand, and gravel, freshwater fish and mollusks, in addition to supporting crops such as fruit trees (Shimada, 1976, 41; Turner & Klaus, 2020, 37). The final zone is the valley flanks. This zone, between the valley floor and the

foothills of the mountains, has subtropical trees and scrub that make it ideal for herding (Shimada, 1976, 54-62; Turner & Klaus, 2020, 38).

In the Reque and La Leche River valleys, there exist two additional microenvironments not found elsewhere in the Lambayeque Valley Complex. In what should be a littoral zone at the mouth of the Reque River, a lagoon and marsh microenvironment exist instead. This microenvironment is biodiverse and has been used for agriculture (Turner & Klaus, 2020, 36). In the La Leche drainage, a semitropical dry forest microenvironment supports a myriad of organisms more commonly found in the Amazon (Turner & Klaus, 2020, 37).

The weather along the north coast is always variable, with some years being extremely dry and others extremely wet. Much (although not all) of this variability comes from the La Niña and El Niño Southern Oscillation (ENSO) phenomena. La Niña events tend to be milder than El Niño events and occur when the Pacific basin cools, causing the Peruvian coast to become drier (Cai et al., 2015; Sandweiss & Maasch, 2020). There are three different El Niño events, including El Niño Modoki, the coastal El Niño, and the better-known Eastern Pacific El Niño. The Eastern Pacific El Niño occurs when the Central Pacific warms, and this warm water propagates to the east along the coast of South America (Sandweiss & Maasch, 2020). The warmed coastal waters result in convective storms throughout the desert that can cause extensive flooding and damage (Sandweiss & Maasch, 2020). El Niño Modokis also form in the Central Pacific, but this warmed water does not travel east to the South American coast. As such, they act more like a mild La Niña and cause a slight decrease in precipitation (Sandweiss & Maasch, 2020). As Modoki events typically have a mild impact on weather, they will not be discussed further. Coastal El Niños form when the water along the coast of South America is warmed, but the Pacific basin remains cool (Hu, Huang, Zhu, Kumar, & McPhaden, 2018). Despite having different etiologies, coastal and Eastern Pacific El Niños have almost identical impacts on the Peruvian coast, with the exception that the coastal variety tends to only last a few months as opposed to around a year (Hu et al., 2018; Sandweiss

& Maasch, 2020). Because of their similar impacts, I include both varieties when I refer to the term El Niño.

Although described as events, the El Niño phenomena occurs over a long period of time, often for over a year. As a result, the consequences noted below are not the consequence of a bad storm one weekend but are rather the culminative result of steady rain for up to a few months on end. El Niños cause excessive rainfall below 1000 meters above sea level (masl), which can cause flooding in the valleys (Hu et al., 2018; Sandweiss & Maasch, 2020). This flooding and the resulting standing water has the capability to physically destroy crops, fields, and infrastructure (Billman & Huckleberry, 2008; Hayashida, 2006). Destroyed fields and infrastructure creates an environment whereby disease can flourish, while the destruction of crops leads to a more vulnerable population (A. S. Gagnon, Smoyer-Tomic, & Bush, 2002; McMichael, 2012). Floods also result in pests such as mice and insects invading fields and consuming remaining crops, again depleting the available food and bringing diseases into contact with the general population (A. S. Gagnon et al., 2002; Sandweiss & Maasch, 2020). Today, epidemics of malaria, dengue, Zika, and chikungunya are known to follow El Niño events, and endogenous diseases such as bartonellosis would have spread similarly (A. S. Gagnon et al., 2002; Rodriguez-Morata et al., 2018; Sandweiss & Maasch, 2020). Flooded paths and roads hinder the movement of people, decreasing a community's ability to get help from an outside source (C. M. Gagnon, Boswell, & Mullins, 2017).

El Niños negatively impact the human environment in ways not directly related to flooding. Soil and rocks that erode during floods are often carried down to the ocean, where they are broken down and deposited back on land as sand. Over time, this sand can build up and encroach on irrigatable fields, resulting in a loss of farmland (Moseley, 2001, p. 225). The warm ocean water that causes El Niños in the first place tampers down the cooler upwelling of the Humboldt current, which results in a decrease in marine biomass from plankton to marine mammals to sea birds (UCAR/NOAA, 1994).

Although El Niños have destructive and potentially lethal effects, they also have beneficial outcomes. For instance, although sediment is eroded from irrigation canals during flooding, this sediment is later deposited in the fields, replenishing the soil (Nordt, Hayashida, Hallmark, & Crawford, 2004). Over time, the continuous deposition of sediment can create elevated areas not susceptible to flooding (Pluta, 2015; Sandweiss & Maasch, 2020). In the *lomas* region between 200 and 900 masl, El Niño events cause an explosion of growth amongst the plants that grow there (Dillon & Rundel, 1990). Some of these plants are edible, some can be utilized for wood, and others for animal fodder. Of particular importance is the *algarrobo* tree which has both edible and woody components. El Niños are a necessary part of the tree's lifecycle, and without the periodic flooding this resource would not exist at all (Sandweiss & Maasch, 2020). Finally, although the decreased upwelling of cold water caused by El Niños results in decreased biomass, this change in marine environment also encourages new species to temporarily move in (Marcus, Flannery, Sommer, & Reynolds, 2020). As a result, El Niños generate increased diversity in the ocean that can be utilized by fishers.

It should be noted that El Niños and extreme weather are not tightly correlated events. El Niños do not always cause flooding, and flooding can occur without El Niños. Because most of the water running through the valleys comes from glacial and rain runoff in the highlands, excess water from these sources can result in flooding without extra El Niño-related rainfall in the valleys themselves (Billman & Huckleberry, 2008). Moreover, even if El Niño-related rainfall saturates a valley, if it does not overcome a watershed, it may not cause flooding (Waylen & Caviedes, 1986). In addition, although El Niños occur over the whole north coast, the risk level of each individual valley varies (Billman & Huckleberry, 2008; Sandweiss & Maasch, 2020). Factors such as the slope, drainage density, and surficial geology can impact how much water is received and how it travels through the valleys. Valleys that have large, low altitude tributary catchment areas are more likely to experience flooding during an ENSO event than those that do not (Waylen & Caviedes, 1986). So, just because one valley experiences extreme flooding

does not mean that the next valley over will too. Even though flooding events and El Niños are not always linked, major flooding events will be referred to as El Niño events for simplicity unless otherwise stated.

3.3 Cultural Ecology

While the environment presents a baseline for the resources available to a given population, human creativity and culture mediate how these resources are used. Cultural behaviors can act as adaptations to the environment and help populations to overcome biological limitations, such as the use of dams in the western United States to contain river water for later use. Conversely, cultural behaviors can act as a maladaptations to the environment, such as the use of water-guzzling lawns in the drought-stricken Western USA. In the Andes, this ability to modify the environment resulted in a diverse array of culturally rich societies who thrived in environmentally challenging spaces.

Perhaps one of the best-known adaptations to the environment in the Andes is the use of irrigation canals to channel both river and flood waters for human use. The first irrigation canals are thought to have been constructed around 1800 BCE (Hayashida, 2006). Typically, canals were built near the necks of the foothills and diverted water to the fields throughout the valley. However, in tumultuous times they could also be built in more remote areas, both to take advantage of the occasional rains and to create fields in better protected areas (Dillehay & Kolata, 2004). The canals were most effective in valleys with ample river-flow and wide, low-gradient valleys, such as the Lambayeque Valley Complex (Hayashida, 2006; Nordt et al., 2004). The Lambayeque Valley Complex is so well suited for irrigation that under the Mid-Late Sicán polity (1000-1375) a third of the total population and a third of arable land along the entire Peruvian coast was located here (Kosok, 1965). The use of canals increased the amount of arable land that could be dedicated to agriculture, which in turn led to greater foodstuff production that could support larger populations and complex hierarchical systems (Billman, 2002;

Huckleberry, Hayashida, & Johnson, 2012). The use of irrigation canals represents a continuum throughout Andean history, with the use and expansion of canals continuing through the rise and fall of various cultures (Hayashida, 2006; Huckleberry et al., 2012).

Irrigation canals were also useful for mitigating and exploiting the impacts of El Niño and other flooding events. At the site of Pampa de Mocan, located along the Chicama River, irrigation canals were converted to flood diversion canals during periods of excessive rainfall (Caramanica et al., 2020). The converted canals then deposited floodwaters into prepared floodwater fields, which were typically unable to be irrigated by normal canal usage. As a result, north coast populations were able to capitalize on the flooding caused by El Niños and grow a myriad of crops in otherwise inhospitable land. This practice was so effective that it continues in Peru today (Shimada, 1994, p. 52). Despite their complexity, irrigation canals were relatively easy to fix, meaning that damaged canals were only inoperable for a short period of time (Billman & Huckleberry, 2008).

The domestication of animals, including camelids such as llamas and alpacas and guinea pigs (or *cuy*) gave Andean populations greater access to and control over these important resources. While both camelids and *cuy* were raised as a sources of protein and for religious sacrifice (Beresford-Jones et al., 2015; Dufour et al., 2014), camelids also served as sources of wool for textiles, manure for fertilizer (along with *guano*) and possibly as a fuel source, and the transportation of goods over land (Dufour et al., 2014; Santana-Sagredo et al., 2020; Shimada, 1994b). Camelid textile production is important to provide warmth in what can be a cold environment, especially as there is not an abundance of other flammable fuel sources (Moran, 2008, p. 175). Beyond the practical nature of Andean textiles, they also serve as identity markers for individuals and the community (Lopez Campeny & Romano, 2020). In pre-Hispanic times, the only way to move goods overland was to either carry them oneself or to use a camelid. As such, the use of camelid caravans was imperative to exchanging a large quantity of goods within and between highland and coastal regions (Dufour et al., 2014; Santana-Sagredo et al., 2020).

Today, camelids are typically herded at higher elevations. However, camelids have historically been herded at lower elevations for thousands of years, likely made possible by the use of maize fodder (Dufour et al., 2014; Santana-Sagredo et al., 2020). The ability to herd and breed camelids within the valleys instead of relying on camelids raised and herded in the highlands would have provided agency and an economic advantage to populations residing in the valleys.

The rising elevation of the valleys and highlands on the western slopes of the Andes results in many stacked microenvironments that contain a diverse array of resources to be utilized (Moseley, 2001, p. 30). The exchange of goods allowed populations at various altitudes and at various places along the coast to have access to this diverse array of foods, fuel, and other goods. For instance, plants such as quinoa, maize, and potatoes were best grown at higher altitudes, while marine resources and other vegetables including squashes, beans, and fruits were better grown along the coast (Turner & Klaus, 2020, p. 39-42). The movement of goods around the Andes was especially important for agriculture along the north coast, as all of the major domesticated crops, including maize, were introduced from elsewhere in the Andes (Turner & Klaus, 2020, p. 180).

Political and social organization also played a large role in the distribution and usage of goods. In the Andes, social structures have been critical for resource management. Along the north coast, these social structures known as *parcialidades* were comprised of extant kinships and based around economic specialization (Shimada, 2001). Economic specialties included salt-makers, potters, and *chicha* (a fermented maize drink) brewers to list a few (Shimada, 1994b, p. 54). Different groups resided in separate communities, which encouraged regional economic interaction. Thus, a system of cooperation for mutual benefit existed. Group identity was often maintained via distinctive dress, religious beliefs and practices, and sometimes even temples (Shimada, 1981). Higher levels of nested organization existed, such that a pair of nobles lead each moiety and many of the leaders operated on multiple levels of leadership with a single *curaca* or lord on top (Klaus, Shimada, et al., 2017; Netherly, 1990).

Parcialidades were similar to *ayllus*, which are descendant or supposed-descendant based clans tied to the sacred landscape and found further to the south (Jenkins, 2001).

Maladaptive cultural behaviors also existed and increased the stress on segments of the population. For instance, the emergence of socioeconomic inequality created a framework that dictated what resources people could use. These resources include the types, quantity, and quality of foods one had access to, in addition to the quality of living spaces. Poor diets, such as those based primarily on maize, and unsanitary living conditions made individuals more susceptible to disease and stress (Gijseghem, 2001; Shimada et al., 2004). This inequality is especially evident during the Middle Sicán period (900-1100 CE), whereby non-elite individuals exhibited more evidence of general stress, infection, and joint disease than sampled elite individuals (Klaus, Shimada, et al., 2017). Differences in diet and sanitation were likely in part responsible for the different lived experiences during the Middle Sicán (Shimada et al., 2004).

Behaviors that caused the movement of people also encouraged the spread of diseases. For instance, Kiracofe & Marr (2008) found that a variety of migrations across the Inka empire led to a surge in bartonellosis cases, a disease endemic to the Andes. The movement of Inka armies, traders, the forced relocation of peoples across the Andes, and the movement of people for construction purposes generated conditions favorable to the expansion of bartonellosis. First, many populations who had never been exposed to the disease were moved to endemic areas, while those from endemic areas brought the disease with them as they moved to non-endemic regions. Secondly, the use of stone and adobe supported large populations of sand flies, whose bites spread the disease. And finally, both drought and El Niños are hypothesized to increase the prevalence of this disease. Other diseases are similarly impacted by human behavior.

Despite the extremes in weather and altitude, the Andean environment provides vast quantities of diverse resources to be harnessed and consumed. From the rich marine ecosystem right off the coast

to the staggered growth of plants and animals in the many microenvironments, the north coast is truly a paradise ripe with potential. This potential has been harnessed for millennium by those residing in the area, with expansions in irrigation, herding, and social systems fostering the growth of cultures and eventual states.

4 CULTURAL EVOLUTION IN NORTH COASTAL PERU

4.1 Introduction

As mentioned in the previous chapter, the north coast, with the Lambayeque Valley Complex in particular, can be an environmentally challenging place in which to make a living. However, over the past 14,000 years the inhabitants of this land have not only survived but flourished, creating powerful and distinctive cultures that continue to fascinate us today. A timeline of these cultures and map of the area is included in Figures 1 and 2. From the Formative era (3500-200 BCE) to the arrival of the Spanish in 1532, pre-Hispanic cultures constructed massive urban works and irrigation canals, supporting large populations and leaving a complex built environment behind for archaeologists to study. The artifacts and mortuary contexts that have come from this region are equally complex and varied. Unfortunately, extensive looting at many of these sites has disturbed and scattered these finds throughout the world, most often lacking provenience. As such, studies utilizing undisturbed sites are even more important for learning about the history of this region.

While this study primarily focuses on the Late Moche (550-850 CE), individuals from the Formative (3500-200 BCE), Late Sicán (1100-1375 CE) are also considered. As such, this section provides a generalized overview of the history along the north coast with a focus on the Lambayeque Valley Complex when possible. The chapter is divided by the cultures prior to the Moche, the Moche, and the cultures that followed.

4.2 Developments on the North Coast Prior to the Moche

One of the first major cultures on the north coast was the Paiján who inhabited the area between 8,500 and 11,000 years ago. Taking advantage of the rich marine resources and varied microenvironments, the Paiján were a foraging people who gradually spent longer periods of time at

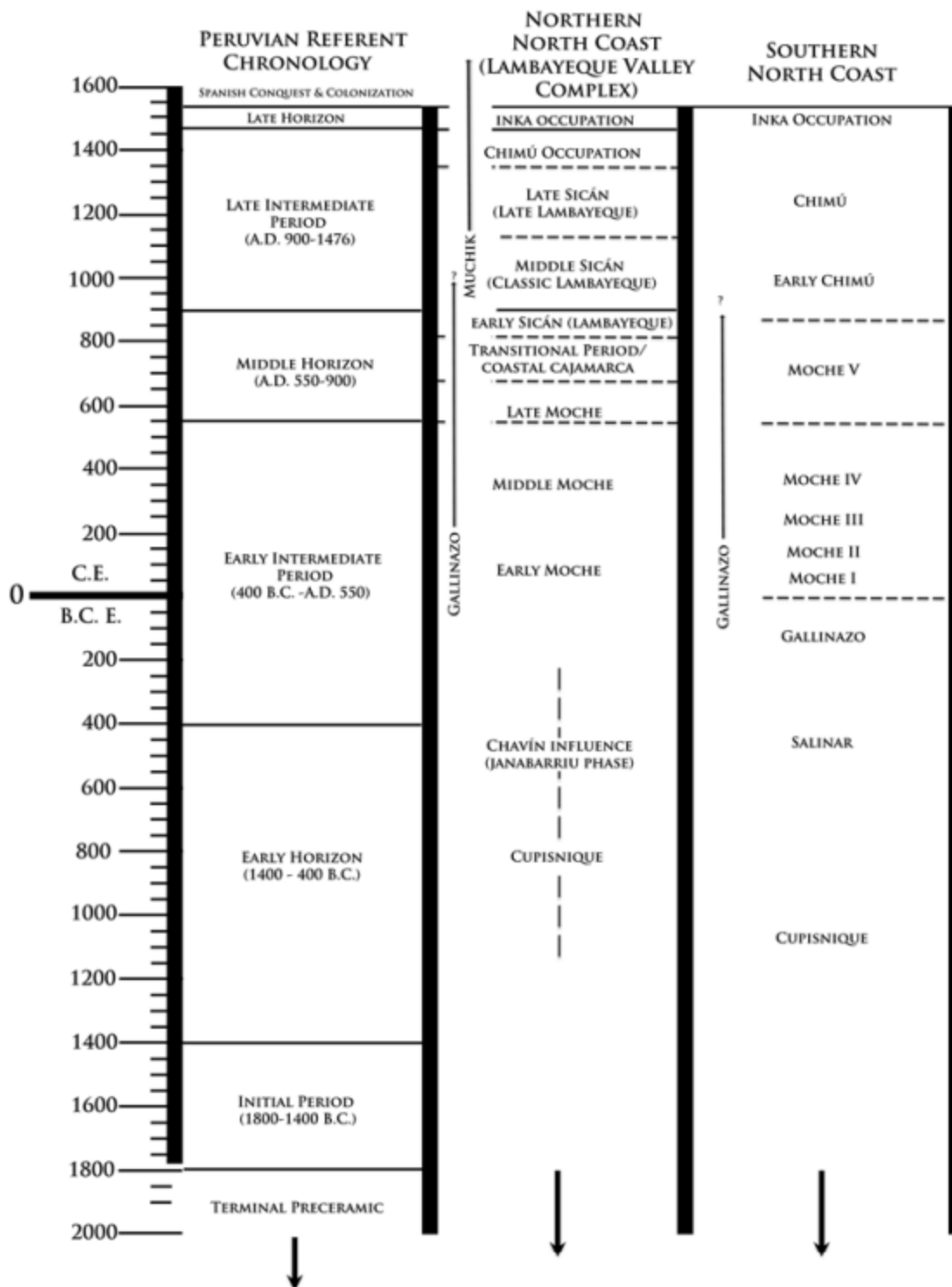


Figure 1: Timeline of occupation along the north coast of Peru. Figure from Turner and Klaus (2020)

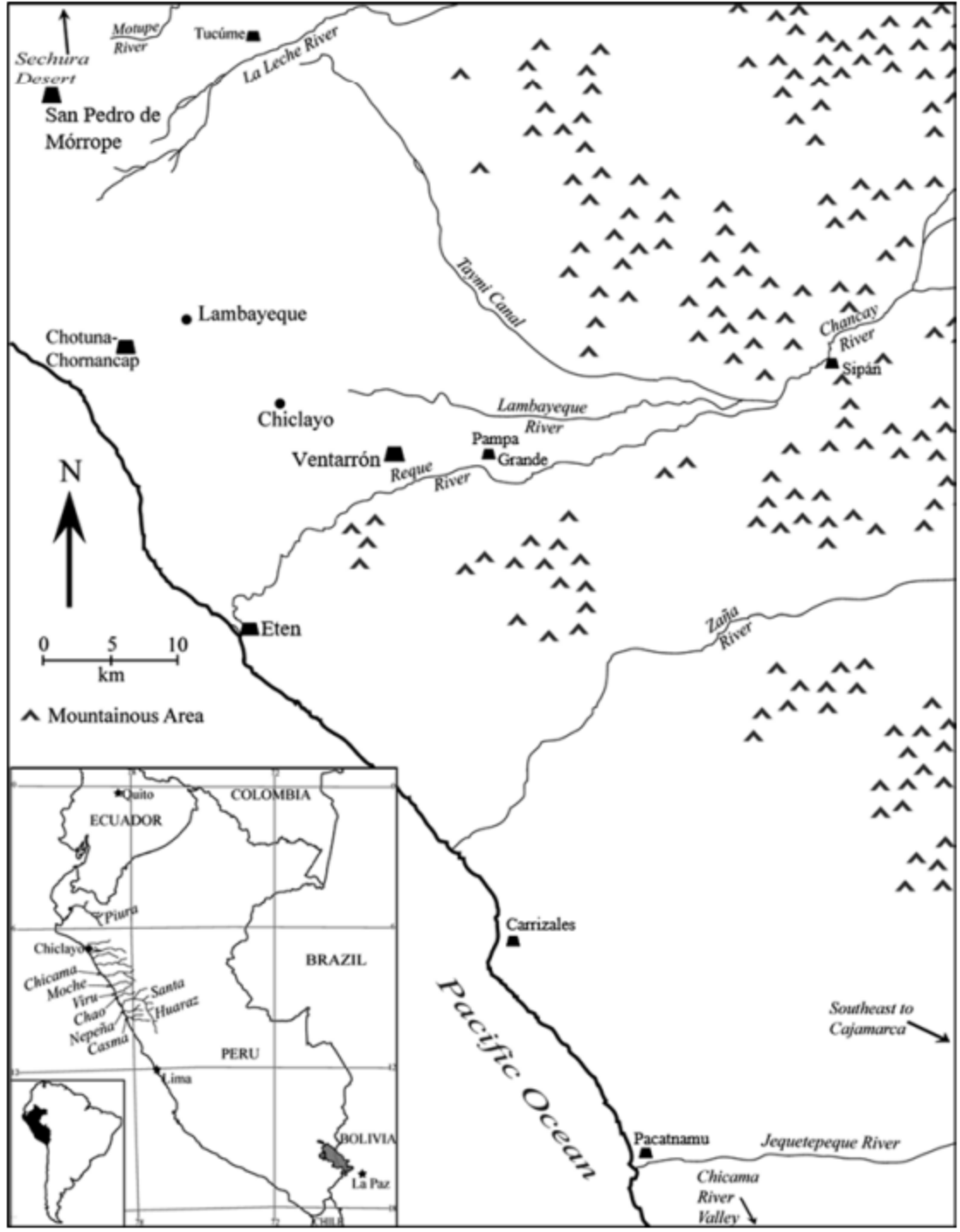


Figure 2: A map of the Lambayeque Valley Complex, including Ventarrón and Eten. Credit: Turner & Klaus (2020).

their settlements (Dillehay, 2013). In the Lambayeque Valley Complex, the first evidence of habitation dates to around 8,000 years ago (Alva Meneses, 2013). Although sedentary agriculture was gradually developed between 6000-4000 BCE, a heavy reliance on marine resources remained. In fact, many of the early cultivated crops, including cotton and gourds, were used to make tools for fishing. It was not until around 3500 BCE that true sedentism began, partially spurred by an increase in population resulting from agricultural technology including simple irrigation and food storage, in addition to craft specialization and elaborated trade routes (Dillehay, 2013). Despite this, a principal focus on foods found in the local environment and marine resources continued well into Early Horizon (900-200 BCE) and Early Intermediate Period (200 BCE-600 CE) (Coutts, Chu, & Krigbaum, 2011; Washburn et al., 2020). Although the population became sedentary in rural environments, urban environments did not emerge as they did elsewhere in the world. Instead, the first large ceremonial monuments were constructed in this area more as ritual centers to be visited than urban centers in which to permanently reside (Dillehay, 2013). Despite some evidence for social stratification, including house size and burial treatment, overall social distinctions appear to remain minimal in this period, with the construction of monuments having been a communal effort and not one led by an empowered individual (Dillehay, 2013; Elera, 1998).

Around the beginning of the Early Horizon, the Cupisnique culture (1500-600/500 BCE) rose to prominence along the north coast, followed by the Salinar (400-1 BCE) and Gallinazo (1-200 CE) occupations. The Cupisnique culture stretched from the La Leche down to the Moche valley, with a core region centered around the Lambayeque Valley Complex and the Chicama and Jequetepeque Valleys. During the Cupisnique occupation, the use of ceramics became widespread and decorations depicting humans, plants, animals (especially stylized felines), and supernatural entities flourished (Turner & Klaus, 2020, p. 53). Although a multitude of separate chiefdom-based polities spanned the north coast, a common religion and ideology served to unite those under this culture (Elera, 1998). The Cupisnique

reached two important milestones during this time: metal working and rising social inequality. Metal working was used to produce precious metal objects such that could be worn by humans, and has been interpreted as a sign of social inequality (Onuki, 2013; Turner & Klaus, 2020, p. 53). Evidence of social inequality also includes differences with settlement hierarchy and interments (Elera, 1998). Despite the inequality that was beginning to form, violence between groups appears to have been minimal (Arkush & Tung, 2013) and co-operation between groups to build monumental architecture may have occurred (Ikehara, 2021).

The decline of the Cupisnique is still poorly understood and is argued to have ended around 600/500 BCE, due at least in part to environmental pressures created by a severe El Niño and possible tsunami events (Elera, 1998). The subsequent Salinar influence stretched from the Piura valley in the north to the Nepeña valley in the south, with a center around the Chicama to the Santa valleys. An escalation in tension and violence is noted during this time period with evidence for the first defensive fortifications occurring (Ikehara, 2021; J. F. Millaire, 2020). In the Lambayeque Valley Complex, this tension has been interpreted as a struggle over resource access between the Salinar and Cupisnique descendants still residing in the valley (Turner & Klaus, 2020, p. 54).

Following the strife from the end of the first millennium BCE, the Gallinazo culture emerged. Evidence of Gallinazo culture has been noted across almost the entirety of the north coast, with emphasis from the Chicama to Santa valleys. Like the Cupisnique, the Gallinazo were a chiefdom-based society based across multiple valleys (J.-F. Millaire, 2009). However, the Gallinazo were more centralized and, in the Moche valley, one Gallinazo chiefdom controlled the entire valley (Billman, 1999). An intensification of maize growth and consumption began during this period, resulting from an increase in irrigation canals and possibly the use of fertilizers such as *guano* or manure, shorter fallowing periods, and/or the introduction of more productive strains of maize (Billman, 1999; Gagnon & Wiesen, 2013; Lambert et al., 2012). Building on the advancements in agriculture and irrigation that developed

between the Cupisnique to the Gallinazo, the Moche would utilize religion and surplus resources to build what is today known as an iconic culture (Benson, 2012; Billman, 2002).

4.3 *Moche North Coast Developments*

The Moche culture emerged around 100 CE, likely concurrently along multiple locations along the north coast. Although previous research argued that the Moche replaced the existing Gallinazo culture, recent studies have shown a more complicated relationship. It is now understood that in some cases, Gallinazo polities “became” Moche while other Gallinazo polities remained quite independent, autonomous, and co-existed with the Moche (Bourget, 2003). The process of Moche expansion and rule relied heavily on the use of gift giving, elite alliances made via marriage, and common religion and art (Klaus et al., 2018; Toyne et al., 2014). It has also been recently argued that the Moche viewed themselves as the descendants of the Cupisnique and used this relationship to validate their rule (Benson, 2012). At its largest, the Moche realm extended from the Piura to the Huarmey river valleys. Generally, there are thought to have been two major spheres of Moche influence, one located in the north and the other the south. Both regions were linked in their religion, ceramic styles, and rule of an elite Moche class, although they would express these characteristics differently at times (Benson, 2012; Chapdelaine, 2011; Quilter, 2002, 2020). At the beginning, the northern Moche polity was centered around Sipán, Úcupe, and Dos Cabezas, while the southern polity was centered around the Moche and Chicama valleys (Shimada, 1994a). By 300 CE regional dominance had shifted to the southern polity. Although the southern polity had an administrative center, also called Moche, presiding over the area, individual chiefdoms still exercised great power and agency (Benson, 2012). During this time, the north consisted of numerous polities centered in the different river valleys. The exact nature of these polities in respect to the southern Moche is unclear, and it has been debated whether the north represented a confederacy of polities allied with the south or quasi-independent rulers subject to the south

(Chapdelaine, 2011; Klaus et al., 2018; Koons, 2015; Quilter, 2002). Following a period of drought and flooding in the 500's, the southern Moche polity declined. The decline of the southern Moche was previously argued to have been the decline of the entirety of Moche culture, but it is now considered that power shifted north to the Lambayeque Valley Complex, where Pampa Grande emerged as the new administrative center (Shimada, 1994b). Other regional centers in the north remained decentralized and distinct from Pampa Grande. From approximately this time until roughly 800/850 CE, the north remained a powerful emblem of the Moche culture (Chapdelaine, 2011; Shimada, 1994b).

The agricultural developments utilized by the Moche were based on the interconnected developments of the preceding cultures and included expanded irrigation canals, standardized fields, the use of manure as fertilizer, and a focus on maize cultivation (Billman, 2002; Gagnon & Wiesen, 2013; Moseley, 2001; Quilter, 2002). On the local level, goods were accepted and redistribution from the general populace to local lords and back again (Benson, 2012, p. 27). Goods were then further distributed via trade networks throughout the valleys. Such a system existed prior to the Moche and likely helped to buffer populations throughout a valley from stressors (Benson, 2012; Netherly, 1990). Increased irrigation opened up more land for cultivation and the use of manure made it more productive, allowing for larger yields of crops. An increased focus on maize cultivation generated a stable crop that could be stored for long periods of time, meaning that it could be transported long distances and/or redistributed at a later date should harvests fail. The ability to redistribute and trade resources in and across valleys helped to promote cooperation (Benson, 2012, p. 27; Chapdelaine, 2011).

The *parcialidad* system functioned so that the small, day-to-day usage and management of canals was conducted by local groups. However, for the construction and maintenance of irrigation canals across large distances, a nested hierarchy combined with the duality of leadership created a system that could draw upon increasingly large amounts of labor but also keep the power of each ruler

in check (Netherly, 1990). In addition, the nested and dual hierarchy lent itself to growth and collapse. Subsections of the system worked the same as the larger system, just on a smaller scale. Conversely, it could easily be scaled up (Netherly, 1990). As such, should a large hierarchy collapse, the small, local subsections could continue functioning.

Intertwined with their advancements in agriculture, the Moche also engaged in camelid herding. Camelids served many important roles in pre-Hispanic societies, including being a source of food, wool, a method of transportation, and an important aspect of many ritual practices (Dufour et al., 2014; Santana-Sagredo et al., 2020). Like canal management, camelid herding was also practiced on the local scale, again placing resources and power into the hands of the masses (Szpak, Millaire, White, & Longstaffe, 2014). Raising camelids allowed households to use their manure to increase crop output (Nordt et al., 2004). This increased output, especially maize, could then be given back to camelids in the form of fodder (Dufour et al., 2014). Thus, under Moche rule many households had access to large quantities of agricultural food and animal resources, of which a portion of tribute could be used to support the urban centers of the Moche elite.

The diets of the Moche reflect existing food patterns from earlier cultures. Maize consumption continued to increase from the preceding centuries (Gagnon & Wiesen, 2013; Lambert et al., 2012). Oral health and isotopic values from the Lambayeque Valley Complex indicate a continued increased consumption of maize into the Middle Horizon (600-1000 CE), although the amount of maize consumed varied per site (Turner & Klaus, 2020, p.150). Marine resources and C₃ plants also continued to factor significantly into people's diets. In a dish excavated from the Late Moche site of Wasi Huachuma, a myriad of ingredients including marine fish, potatoes, maize, llama, and coca point to the consumption of a diverse types of foods from across the Andes (Duke, 2019).

Moche trade networks extended up north into Ecuador and to the south into central Peru, along with up to the highlands and the jungles beyond (Duke, 2019; Shimada et al., 2004; Vaughn, 2006).

Moche elites gained prestige and precious goods via trade, especially that of the *Spondylus* shell from Ecuador (Shimada, 1994b). Commoners also participated in trade and likely relied on their *parcialidad* systems for the reciprocal exchange of goods (Duke, 2019). Socioeconomic standing mediated one's access to goods and resources, which would also mediate their exposure and response to stress. In the capital of Moche, less-well off households had less access to building materials, and as a result their homes were smaller and of poorer quality than those who were better off. In addition, houses that were better off tended to be multi-generational and have more people to draw resources from, suggesting that stronger family networks or *parcialidades* may have helped to increase socioeconomic standing (Gijseghem, 2001). Access to foodstuffs, especially certain types of marine foods, was also mediated by social standing. Again in the capital of Moche, those residing in less-well off quarters ate a large quantity of a disfavored shellfish (Rosello et al., 2001).

Moche religion is complex, with practices varying across site and time. As such, only a brief overview is provided here. The Moche appear to have had a vast array of mythical deities who are often displayed in various themes found on ceramics and on murals (Benson, 2012). Ritual themes of the divine depicted on pottery were enacted by Moche elite, tying the elite with the divine (Chapdelaine, 2011). Mythic attributes were often associated with various plants and animals, and elites used these motifs to showcase their power (Bourget, 2016, p. 311). Following 550 CE, a focus on the sea, both from the organisms and in the events depicted, occurred and will be discussed in more detail later (Jennings, 2008).

The decline of the southern Moche polity occurred around 550 CE, due in part to the most extreme droughts recorded in the region during this century which lasted approximately 30 years (Moseley, 2001, p. 225). As a part of the ENSO cycle, following the drought came extreme flooding, leading to the immediate destruction of buildings and irrigation canals, a loss of topsoil, and eventual sand incursion on agricultural fields (Quilter, 2020; Shimada, 1994b). The destruction and inferred

sociopolitical instability caused by the flooding ushered in the Late Moche period (550-850), a period of reorganization, de-centralization, and increased turmoil in both the northern and southern Moche realms. The responses in each sector to this turmoil differed. In the south, territories south of the Moche valley fell away (Shimada, 1994b). The sacrifice of non-local individuals in the Moche capital suggests conflict that resulted in prisoners and potentially an attempt of the Moche capital to hold onto power (Toyne et al., 2014). However, by the end of the century it appears that the southern Moche people lost confidence in the elite ruling class and may have overthrown the ruling class at the capital of Huacas de Moche (Chapdelaine, 2011; Moseley, 2001; Uceda, 2008). Settlements in the south dispersed into the hinterlands, with one of these new sites, Cerro Galindo, devoting up to 20% of building space to food storage (Bawden, 1996).

In the north, a new Moche center rose to prominence in the Lambayeque Valley Complex. Excavations by Izumi Shimada have found that Pampa Grande, as with many of the sites to the south, was concerned with drought and environmental stress. The site was located at the valley neck, where it had control over irrigation outlets, and this asserted Pampa Grande's political control over water access for much of the region. Elites in the city controlled large numbers of storage facilities clustered around the central mound, Huaca Fortaleza (Shimada, 1994b). While Pampa Grande maintained some links to the Moche past, different architectural canons and importantly, a shift in religion, helped to establish the city as a new power not associated with the failures of the past (Jennings, 2008; Moseley, 2001, p. 226). With the rise of Pampa Grande, many of the entities previously in the Moche pantheon were sidelined and a focus on maritime themes prevailed (Jennings, 2008). Why the sea became the primary focus of this updated religion is unknown, but it is hypothesized that the sea, recovering more quickly from environmental calamities, gained even more importance as a source of stability and abundance (Billman & Huckleberry, 2008; Jennings, 2008; Swenson, 2007).

Even as power concentrated at Pampa Grande, the north remained divided into different polities and decentralized factions across its valleys. It has been hypothesized that the additional pressure caused by the weather caused factions to form along irrigation canal sectors, creating many individual groups struggling to maintain power and create unique, fluid, partible, and even temporary identities (Sutter & Castillo, 2015; Swenson, 2007). In the Jequetepeque Valley, a proliferation of ceremonial sites and agricultural facilities not associated with elites has been interpreted as local units commandeering the Moche legacy and using it to assert their own individual power (Swenson, 2007). In the highlands to the east, climatic instability encouraged migration down to the valleys. Due to the fragmentation, it is argued that these migrants were able to settle after making alliances with the ruling elite (Sutter & Castillo, 2015), although tension over water supply may have still existed.

As in the south, settlements centered at the necks of valleys flourished and agriculture was geared towards taking advantage of changes in weather (Dillehay & Kolata, 2004; Swenson, 2007). Irrigation canals and reservoirs were built in the margins of the valley so that when rains and flooding did occur, extra fields could be managed for increased crop output (Dillehay & Kolata, 2004). Having fields prepped for usage would have also been beneficial as a place to retreat to should strife occur.

The final decline of the Moche occurred around 800-850 CE, likely a combination of climatic pressure and political instability amongst the many factions in the area (Shimada, 1994b; Swenson, 2007). Pampa Grande was burned in a way that is highly consistent with a model of an internal revolt (Shimada, 1994b). The Late Moche period in the north was then a paradoxical period, filled with at first with recovery from climatic stress and religious-political fatigue, but also the flourishing of new sites, ideas, and adaptations to an especially challenging environment.

4.4 Late Pre-Hispanic and Colonial Developments on the North Coast

The Sicán culture, also known as the Lambayeque culture, existed from approximately 800/850-1375 CE. Sicán territory extended from approximately the Chira Valley in the north to the Chicama Valley in the south (Shimada et al., 2004). By the height of the Middle Sicán around 900-1100 CE, an ethnic Muchik identity had formed amongst those residing in the valleys built upon the Moche traditions of the preceding centuries (Klaus, Shimada, et al., 2017). The majority of elite rulers, however, were primarily an ethnic Sicán class that relied on extensive trade (especially of metal), wealth, and highly restricted marriage networks to maintain their power (Klaus, Shimada, et al., 2017; Shimada et al., 2004; Vogel, 2017). The Sicán elite originally portrayed themselves as demigods, ruling from their capital of Sicán. However, following an El Niño event in 1100 CE, the rulers appear to have been violently overthrown and a new capital at Túcume was established (Jennings, 2008; Shimada et al., 2004).

The Sicán built upon and expanded the agricultural and herding infrastructures originally utilized by the Moche. The irrigation canals continued to be operated locally, giving rural populations power over their land (Hayashida, 2006). At the same time, the canals were expanded to place ever more land under the proverbial till (Huckleberry et al., 2012). The herding of camelids continued down in the valleys, providing locals with an array of resources and the means for the Sicán realm to transport goods overland (Santana-Sagredo et al., 2020; Szpak, Millaire, White, Donnan, & Longstaffe, 2018). While socioeconomic differences and climatic variability existed that impacted exposure and response to stress, overall life under the Sicán was notably peaceful (Klaus, Shimada, et al., 2017; Shimada et al., 2004).

This relatively peaceful period was disrupted as the Sicán realm was slowly subsumed by the Chimú from 1350-1400 (Vogel, 2017). The Chimú state began in the Moche and Chicama valleys and had its capital at Chan Chan. In its captured territories, the Chimú exerted greater control over local economies and political networks, although the extent of direct control varied across the valleys

(Dillehay et al., 2022; Hayashida, 2006; Huckleberry et al., 2012). New administrative buildings were constructed, local elites were commandeered to work for the Chimú, and the resettlement of certain populations may have occurred (Dillehay et al., 2022). After a protracted war, the area was finally conquered and incorporated into the Inka empire around 1470 CE (Moseley, 2001, p, 261). During their brief 60-year tenure, the Inka coopted and expanded many of the Chimú's practices including state control of local economies the limited resettlement of populations around the Inka empire (Dillehay et al., 2022; Hayashida, 2006).

The arrival of the Spanish to the Andes resulted in “an invasion, a colonization effort, a social experiment, a religious crusade, and a highly structured economic enterprise” that would drastically change the Andean world (Deagan, 2003, p. 3). The colonization of the New World upended traditional ways of life and resulted in the institution of Catholicism, an economic system geared towards production for the Spanish, a complete reorganization of social structures, and a change in the way people lived their daily lives including where they lived, what they ate, how they treated their dead, and more (Deagan, 2003; Klaus & Alvarez-Calderon, 2017; Turner & Klaus, 2020). Although the effects of colonialism would leave virtually no corner of the world untouched, the impact of contact varied depending on the region, duration, and intensity of the contact (Klaus & Tam, 2009).

In 1532 CE, the Spanish first invaded the Lambayeque Valley Complex (Klaus & Alvarez-Calderon, 2017), initiating centuries of oppressive rule, religious conversion, and economic exploitation (Deagan, 2003). In the beginning, the Spanish exerted control over the region via the *encomienda* system, in which the indigenous population would pay for military protection and instruction in Catholicism by providing the Spanish with taxes and labor (Turner & Klaus, 2020, p. 69). In practice, of course, this was nothing less than enslavement and ethnocide; the system quickly began to fail due to the continued population decline caused by European diseases and unsafe working conditions, as well as local resistance (Klaus & Alvarez-Calderon, 2017; Turner & Klaus, 2020, p. 69). The *encomienda*

system was replaced with the *hacienda* system in the countryside, in which locals were paid wages but often became indebted to the landlord and stuck in a cycle of attempting to pay off their debts, much like the sharecropping system after the American Civil War (Moroni Stewart, 2016).

Spanish administration of colonial Peru burdened the indigenous population with a multitude of stressors. The ranching of European grazers such as cattle, pigs, goats, and sheep resulted in the deterioration of many indigenous crops (Ramirez, 1996). Extensive monoculture focused on water-intensive crops such as alfalfa and later sugar often left little water for local consumption and depleted the soils (Ramirez, 1996). Those working in agricultural settings and mining faced long hours from work quotas, consuming people's energies (Turner & Klaus, 2020, p. 73).

The Spanish also forcibly resettled indigenous communities into planned towns called *reducciones* in order to take over agriculturally productive and/or strategically located lands. *Reducciones* were often located in the hinterlands with poor soils and inadequate irrigation, making it increasingly difficult for locals to eke out a living (Garland et al., 2016; Klaus & Tam, 2009). Disease, unsanitary living quarters, and migration took its toll, and the population declined in the 16th century, before beginning to rebound in the 18th century (Turner & Klaus, 2020, p. 73). In total, these extractive economic policies aimed at providing resources for Spanish elites resulted in the destruction of the *kuraka* class and the reciprocal *parcialidad* system that had existed for hundreds of years. It should be noted that Indigenous groups did resist, with a failed rebellion led by the puppet emperor Manco Inka establishing an Inka polity at Vilcabamba that lasted until 1572 CE (Bauer, Cruz, & Silva, 2015). Even without full-out rebellion, Indigenous groups resisted Colonial rule by fleeing the *encomienda* and *hacienda* systems and refusing to convert to Catholicism, although the latter often resulted in gruesome executions (Turner & Klaus, 2020, p. 74, 83).

The history of the north coast of Peru reflects an intertwining of intra- and inter-valley relationships, which has resulted in the formation of many complex cultures. Although by no means a

direct, lineal relationship, the gradual adaptation of agriculture along with systems of reciprocity laid the basis for ever larger polities to thrive. While the arrival of the Spanish irrevocably changed life along the north coast and the New World at large, life prior to Spanish occupation was diverse and ever-changing in its own right. As such, the archaeological study of the north coast requires that researchers make their interpretations thoroughly grounded in the regional and temporal environment in which they study.

5 RESEARCH DESIGN AND METHODS

5.1 *Objective*

The objective of this study is to examine early life stress in the Lambayeque Valley Complex amongst pre-Hispanic individuals interred at Ventarrón. Specifically, this study utilizes internal enamel microdefects known as Wilson bands, which capture acute stress events in the first few years of life. These acute stressors have often been attributed to gastrointestinal diseases and are frequently linked to the introduction of bacteria in water from complementary feeding or the cessation of weaning (Garland et al., 2016; Klaus et al., 2015). Using Wilson bands, this study follows three fields of inquiry: 1) early life stress patterns of frailty and mortality in pre-Hispanic individuals as detailed in the phenotypic plasticity hypothesis from Chapter 2; 2) differences in early life stress between pre-Hispanic, especially Late Moche samples, and later Colonial samples, and 3) an pre-Hispanic osteobiographical account of how the physical and biocultural environment shaped children's exposure to stress and their ability to survive it.

5.2 *The Ventarrón Archaeological Complex*

The skeletal materials utilized in this study hail from Ventarrón, an archaeological complex located in the lower Reque River Valley, one of the five river valleys that make up the Lambayeque Valley Complex. The site of Ventarrón is situated around a small mountain named Cerro Ventarrón and is adjacent to the modern villages of Ventarrón and Collud. The modern city of Chiclayo, which serves as the regional center, is approximately seven kilometers from the site of Ventarrón (Figure 2). The archaeological complex covers approximately 600 hectares in the lower and mid valley and includes the architectural remains of four *huacas* (ceremonial mounds that often also serve funerary purposes) and their associated temples, residential quarters, and graves (Alva Meneses, 2012, 2013). These *huacas* include that of Ventarrón (named after the site), El Arenal, and the twin-*huaca* site of Collud-Zarpán.

Excavations at the site began in 2007 under the direction of Ignacio Alva Meneses and have supplied evidence of habitation spanning back to the Preceramic Period (3000-1000 BCE). Most major pre-Hispanic cultures on the north coast varyingly occupied this site (Alva Meneses, 2012, 2013). The oldest murals in South America are located at Ventarrón and serve as important resource for understanding early symbolism, religion, and art along the north coast (Alva Meneses, 2013; Wright, Meneses, & Laval, 2015).

Although Ventarrón was described as one of the most important in Peru (Alva Meneses, 2013; Masini & Lasaponara, 2021; Wright et al., 2015), extensive looting of the site has caused significant damage (Alva Meneses & Alva, 2013). Burials and grave goods, including gold artifacts and ceramics, are known to have existed at the site. Looters have been digging and selling these materials for decades, although during the economic downturn of the eighties these digs increased. The discovery of a resplendent tomb at Zarpán by looters in the late eighties resulted in a frenzy of digging such that hundreds of burials were likely removed (Alva Meneses, 2012). The burials across the site were interred well after the construction of the *huacas* and were often topped with stone slabs. These stone slabs made locating burials easier for looters as they were easily distinguishable from the surrounding environment during probing (Alva Meneses, 2012). Some burials looted in the early-mid 20th century have been associated with the site and are currently at the Brüning Archaeological Museum. In addition, scientific excavations have unearthed a few untouched burials for study, although few of these appear to represent the elite individuals who may once have been interred at the site as well (Alva Meneses, 2012). The use of adobe blocks from the site for modern structures by locals has caused further damage to the architecture and some of the murals (Alva Meneses, 2012). A devastating sugar cane field fire in 2017 destroyed parts of the site and the artifacts that were housed there (BBC, 2017; Masini & Lasaponara, 2021).

Despite the damage incurred at the site, excavations have provided important information regarding the four *huacas* and their associated burials. Huaca Ventarrón was built between 3000 BCE and 2800 BCE during the Preceramic Period (3000-2800 BCE). This *huaca* was reconstructed between three and five times, increasing the height of the platform and resulting in three distinct temples. The final phase of construction was completed around 1800 BCE, when the site was abandoned due to flooding. El Arenal was built and later abandoned around the same time as Huaca Ventarrón. It contains the remains of temples and residential dwellings for religious elites (Alva Meneses, 2013). The site of Ventarrón was again occupied a few centuries later with the construction of Huacas Collud and Zarpán, built around 1500 to 1000 BCE by the Cupisnique. The entire site was then abandoned again until the Middle Moche (300-550CE) period, when a small temple complex was built on El Arenal. The last phase of construction on the site occurred during the Middle Sicán period (900-1040/1100 CE) with the creation of new temples at Collud-Zarpán (Alva Meneses, 2012, 2013).

The original constructions of El Arenal and Huacas Ventarrón, Collud, and Zarpán were not meant to serve as a funerary sites; instead, later cultures appear to have been quite possibly asserting their identity by returning their dead to the surrounding ancestral landscape (Turner & Klaus, 2020, p.88). Unfortunately, many of these burial contexts are gone. At Huaca Ventarrón, the presence of a path commonly used by looters protected a few of the Formative and Late Sicán graves underneath. An undiscovered mound in the Arenal Complex revealed 24 burials from the Late Moche period, of which 19 were infants and young children. This find is quite exciting as there are usually fewer child funerary contexts than what is expected at a site along the north coast, and it is believed that children were often interred separately (Klaus, 2018b). The area surrounding this mound show evidence of looting. Despite the intensive looting at Zarpán, the sheer quantity of graves resulted in some still being discovered by researchers (Alva Meneses, 2012). Overall, the burials uncovered by researchers appear to be non-elite and may even represent individuals of a low socioeconomic status.

5.3 Materials and Methods

This project utilized teeth currently housed in the Bioarchaeology Laboratory at Georgia State University. These teeth, consisting of first and second molars, along with premolars have already undergone destructive analysis in an isotopic dietary study (Turner & Klaus, 2020). As a result, most teeth are not complete but are rather large fragments. Prior to the destructive analysis, casts of the teeth were taken for future morphological studies. Fourteen teeth representing fourteen individuals were selected for analysis (Table 1). Teeth were only selected if the cusp exhibited little wear to ensure that no Wilson bands could have been worn away. While this method did ensure that the majority of Wilson bands were observable, it also skewed ages of individuals sampled to the younger side. Although a small sample size, these teeth represent the total number of pre-Hispanic teeth 1) present in the Bioarchaeology Lab and not destroyed during the fire at the site and 2) that fit the strict wear requirements.

Age and sex were estimated by Haagen D. Klaus (Klaus & Tam 2009). The individuals were estimated as biologically male (n=1), female (n=1) or undetermined (n=12) based on standard morphology of the os coxa and the skull. These teeth primarily encompass the Late Moche occupation of the site (n=11), with two individuals from the Formative (1000-400 BCE) and one from the Late Sicán (1100-1375 CE) occupations. The Late Moche individuals were interred at Huaca Arenal (n=5) and Huaca Zarpán (n=6), while the Formative and Late Sicán individuals were interred at Huaca Ventarrón. Only ten of the fourteen individuals used for this study had age-at-death associated with them. The age range for these ten was between two and thirty years, with the majority (n=8) being pre-pubescent.

To study internal enamel microdefects such as Wilson bands, thin sections of each tooth are viewed under a polarized light source. As archaeological dentition can be fragile, prior to thin sectioning the teeth are stabilized by embedding them in epoxy resin (Marks et al., 1996). The methods utilized for this study are based upon modified protocols used in Garland (2020) and Marks, Rose, & Davenport

(1996). The teeth selected were first cleaned of any dirt, grease, and other contaminants in a solution of 91% isopropyl alcohol for approximately twenty-four hours. The teeth were then dehydrated in a 50°C oven for two hours to evaporate any remaining liquid. Afterward, they were secured in 30 mL plastic medicine cups labial side up using tape and jewelry wire. Small batches of Struers® slow curing and transparent EpoFix® epoxy resin and hardener were mixed at a ratio of 15:2 mL under the fume hood. Each batch was then spun in a centrifuge for four minutes at 2400 rpm to ensure an even mixture and to remove any remaining air bubbles. The epoxy resin was slowly poured over the teeth to keep bubbles from forming and allowed to cure overnight in the desiccator cabinet.

The teeth were thin sectioned utilizing the Buehler Isomer 1000 diamond-blade microtome saw. Three longitudinal buccal-lingual cuts were made, resulting in two thin sections that were ~300-400 μ in thickness. Having two slides provided a back-up in case one was subsequently damaged (Garland, 2014). The teeth were immediately cleaned with isopropyl alcohol and attached to a slide with Duro superglue. Finally, the teeth were acid etched by wiping 1M HCl on the surface of each slice for a few seconds and then rinsing them. Acid etching highlights the different orientations of the prisms more clearly and removes any scratches that may have formed during the slicing and grinding processes (Marks et al., 1996). The slides were analyzed under a polarized light microscope in the Geosciences Lab also located at Georgia State University.

The thin sections from the fourteen selected teeth were viewed under a polarized light microscope. General descriptions of the individuals are included in Table 1. The presence or absence of Wilson bands was noted with either a 0 or 1, and then the total number of Wilson bands was counted for each individual. These data were then compiled with previously recorded data regarding childhood stress including cribra orbitalia, porotic hyperostosis, linear enamel hypoplasias, and periostitis in Table 2. Striae of Retzius were only considered Wilson bands if they followed the criteria set out by FitzGerald et al. (2006), which describes Wilson bands as accentuated and observable for at least 75% of the

distance between the dentin-enamel junction and the occlusal surface or visible for a least 75% of the distance around the dentine horns in the cusps. For first molars, the age at formation was calculated by counting the striae of Retzius between the neonatal line and the Wilson band. For the second molars and premolars, the position of the Wilson band on the tooth was compared to the age of tooth formation by Smith (1991) and a general age range created. The prevalence of Wilson bands was calculated by dividing the number of individuals by the number of individuals presenting at least one Wilson band. The mean number of Wilson bands per person was calculated by dividing the number of Wilson bands by the number of individuals. The average age of death was calculated among the cohort of individuals who had been assigned an age-at-death.

Table 1: General descriptive information regarding the individuals analyzed.

Mortuary No.	Cultural Affiliation	Age	Sex
8	Formative	12	N/A
14	Late Sicán	22	F
26	Formative	N/A	N/A
32	Late Moche	N/A	N/A
36	Late Moche	3	N/A
39	Late Moche	6	N/A
50	Late Moche	3	N/A
74	Late Moche	10	N/A
80	Late Moche	N/A	N/A
100	Late Moche	N/A	N/A
111	Late Moche	5	N/A
113	Late Moche	10	N/A
117	Late Moche	30	M
120	Late Moche	2	N/A

5.4 Hypotheses and Expected Results

Utilizing the methods and archaeological sample above, two central hypotheses are explored, along with an interpretive osteobiographical objective. These two hypotheses are imbedded in the physical and biocultural environment of the populations from whence the study samples are drawn and aim to further the existing literature regarding the phenotypic plasticity hypothesis and early life stress across time in the Lambayeque Valley Complex. Due to the small sample size used in this study,

statistical tests are not always feasible. However, whenever they are conducted a significance level of $p < 0.05$ will be used in accordance to comparable studies (Garland et al., 2016; Turner & Klaus, 2020).

H₁: Individuals with one or more observed Wilson bands will exhibit a lower estimated mean age-at-death than individuals with no observed Wilson bands.

This hypothesis assesses if the phenotypic plasticity hypothesis, a modification of the Barker hypothesis discussed in Chapter 2, applies to the pre-Hispanic individuals utilized in this study with known ages at death ($n=10$). According to the phenotypic plasticity hypothesis, when faced with a stressful early life environment, the body intentionally invests in phenotypes that promote short-term survival by reallocating energy and resources away from biological processes that would support longevity. As such, it is expected that those exhibiting one or more Wilson band should also have a lower age-at-death than those who perished without a Wilson band. Garland (2014) found such a pattern amongst Colonial individuals residing in the Lambayeque Valley Complex, suggesting that a similar pattern might be found in pre-Hispanic populations. Height has also been used to explore the effects of childhood stress with the idea that cumulative stress as a child will divert resources away from growing, resulting in shorter stature (Temple, 2008). However, when height is used to represent a tradeoff in both pre-Hispanic and Hispanic individuals, no difference in adult stature has been found between those with or without enamel hypoplasias (Klaus, 2018b). These two studies suggest that in Colonial populations, acute childhood stress, as seen in Wilson bands, results in increased mortality, while cumulative stress, as evidenced by height, is not only survivable but can be overcome. Does acute, episodic stress in pre-Hispanic populations follow a similar pattern, whereby those with Wilson bands will have earlier mortality? Or, were populations better able to adapt and survive these stressors? In addition, is early life stress and early mortality a pattern that carries through Andean history through

Colonial times? Here, Mann-Whitney U tests were conducted for age-at-death between those with and without at least one Wilson band using individuals from this study and Garland et al. (2016).

H₂: The pre-Hispanic cohorts in this study will exhibit lower Wilson band averages than previously studied Colonial-period cohorts.

This hypothesis aims to expand the existing literature regarding early life stress in the region. A previous study by Garland et al. (2016) focusing on early life stress in the Colonial period found a higher prevalence of Wilson bands in the Early Colonial phase than Middle/Late Colonial phases and interpreted these data to reflect an acclimation to life under Spanish oppression. However, there are limited pre-Colonial data with which to compare these results. While the arrival of the Spanish certainly upended life across the Andes, life prior to the arrival of the Spanish was not without hardships either. Environmental calamities including droughts and flooding occurred as well as political upheaval and revolts (Ikehara, 2021; Jennings, 2008; Shimada, 1994b). Infectious diseases endemic to the Andes were prevalent as well (Toyne, Murphy, & Klaus, 2020; Verano, 1997a). So, in regards to acute early life stressors, how significantly did it change between Colonial and pre-Hispanic sampled populations? Mann-Whitney U tests of Wilson band prevalence between the total pre-Hispanic cohorts and those from Garland et al. (2016) were conducted to determine if exposure to stress changed significantly between the periods. A Kruskal-Wallis test of age-at-death between all of the cohorts was also conducted to determine if longevity significantly changed over time.

The final objective of this study is to provide an osteobiographical account for pre-Hispanic life at Ventarrón, with a focus on the Late Moche cohort. Combined with osteological data previously gathered from these individuals, information regarding culture, politics, and the environment during this time are used to examine the ways environmental stress was mediated or exacerbated. As reviewed in Chapter 4, the Late Moche period along the north coast was a time of climatic and political upheaval and

decentralization. Yet, as evidenced in Chapter 3, the ability of north coast populations to overcome and thrive in such an environment is not to be underestimated. Settlements situated around irrigation necks flourished, helping to ensure a steady supply of water to its inhabitants (Shimada, 1994b). The spread of irrigation canals into the hinterlands ensured that any extra rainfall would be taken advantage of (Dillehay & Kolata, 2004). Since Wilson band formation is largely associated with acute episodic stressors such as those contracted from drinking contaminated water, how successful were the Late Moche in preventing exposure to disease?

6 RESULTS AND DISCUSSION

6.1 Thin Sectioning Results

Descriptive data following the criteria outlined in Chapter 5 are included in Tables 2 and 3. Overall, 71.40% of the combined cohort exhibited at least one Wilson band for an average of 1.2 per person. None of the individuals from either the Late Sicán or Formative time periods exhibited any Wilson bands, while 90.90% the Late Moche cohort did for an average of 1.5 Wilson bands per person. The average age of death for the combined cohorts was 10.3, although it increased for non-Moche cohorts and for individuals not exhibiting Wilson bands. For the Moche cohort and those exhibiting Wilson bands, the average age decreased. All aged individuals exhibiting Wilson bands (n=7) died prior to the age of 12, while all aged individuals not displaying Wilson bands (n=3) died at or after the age of 12. The combined cohort displayed a uniform distribution of Wilson band frequency, while the Late Moche cohort exhibited a bell curve (or normal) distribution (Figure 3).

Table 2: Wilson band and childhood stress data for Formative, Late Sicán, and Late Moche individuals (WB=Wilson band, EH=enamel hypoplasias, CO=cribra orbitalia, PH=porotic hyperostosis, PERIOST=periostitis) (0=not present, 1=present, N/A=no data). EH, CO, PH, PERIOST data from Klaus (2018a)

Mortuary No.	Presence of Wb	No. of Wb	EH	CO	PH	PERIOST
8	0	0	N/A	1	1	0
14	0	0	0	0	1	0
26	0	0	N/A	N/A	N/A	0
32	1	1	N/A	N/A	N/A	0
36	1	1	0	0	0	0
39	1	3	N/A	N/A	N/A	0
50	1	2	0	0	0	0
74	1	2	1	0	1	0
80	1	2	N/A	N/A	N/A	0
100	1	2	0	0	0	0
111	1	2	0	0	0	0
113	1	1	1	N/A	N/A	0
117	0	0	1	0	1	0
120	1	1	N/A	N/A	N/A	0

Table 3: Descriptive statistics for the combined and individual cohorts. The top section is based upon total individuals in cohort and the middle section is based off of the number of aged individuals. Wb=Wilson band.

	Total	Formative	Late Moche	Late Sicán
No. of individuals	14	2	11	1
% of individuals w/ at least 1 Wb	71.40%	0.00%	90.90%	0.00%
Mean number of Wilson bands	1.2	0	1.5	0
No. of aged individual	10	1	8	1
% w/Wb, dead before 12	70%	0.00%	87.50%	0.00%
% w/Wb, alive for/after 12	0.00%	0.00%	0.00%	0.00%
% w/out Wb, dead before 12	0.00%	0.00%	0.00%	0.00%
% w/out Wb, alive for/after 12	30%	100%	12.50%	100%
Average age of death	10.3	12	8.6	22
Average age of death w/Wb	5.57	N/A	5.57	N/A
Average age of death w/out Wb	21.33	12	30	22

The teeth selected for this study included first and second molars as well as premolars. The crowns of these teeth span a developmental age of a few months before birth to around 6.5 years of age. Age at Wilson band formation is detailed in Table 4. Only one aged individual had a tooth sampled that predated their death by more than two years. Excluding the individual with the unspecified molar and the individual with the tooth predating their death, age-at-formation strongly associates with age-at-death ($R^2=0.843$). Including the individual with the predating tooth brings the association down ($R^2=0.0154$) (Figure 4). However, the small sample size ($n=5$) requires more future analysis to confirm this pattern.

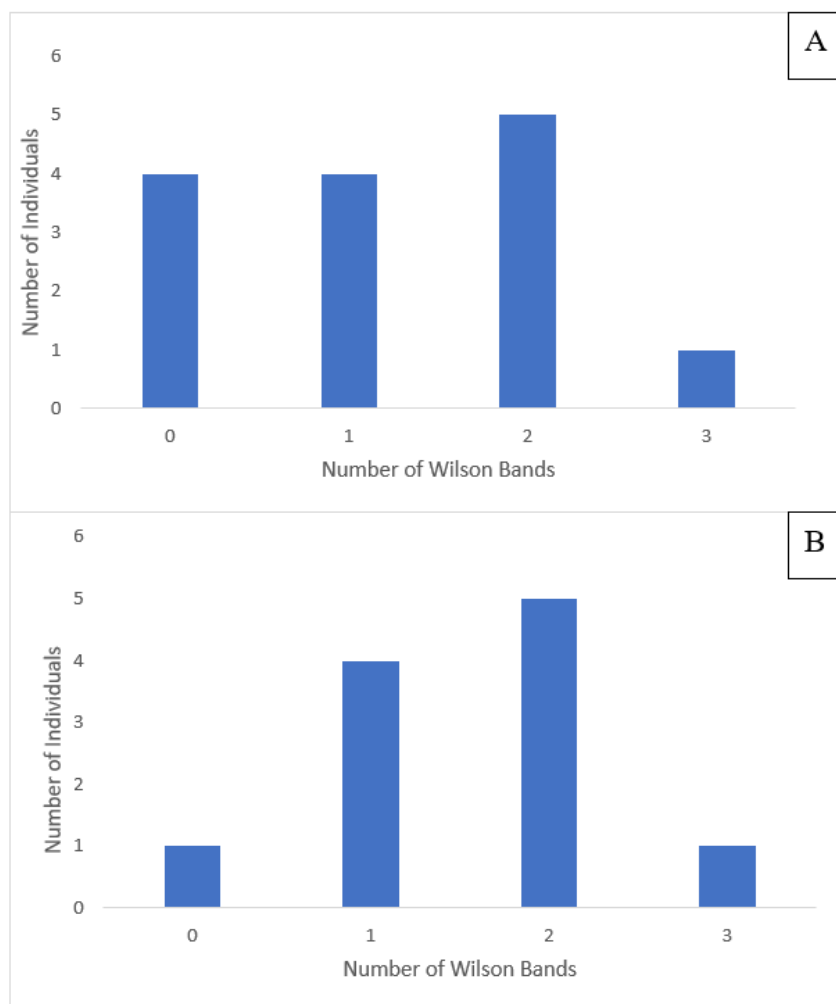


Figure 3: Frequency of Wilson band occurrence for combined Formative, Late Sicán, and Late Moche (A) and Late Moche only (B)

Table 4: Approximate age at Wilson band formation for individuals exhibiting at least one Wilson band. The bolded numbers in the age grouping is the more approximate age.

Mortuary No.	Tooth	Approx. Age at Formation (years)	Frequency of Wilson Bands	Age-at-death
32	LM1	0.8	1	N/A
36	UP2	2 -3.5	1	3
39	UP3	3 -4.5	3	6
50	UP2	2 -3	2	3
74	UM1	0.5, 0.6	2	10
80	LM2	3.5-5	2	N/A
100	LP2	5	2	N/A
111	UM2	4- 5	2	5
113	M	0-11	1	10
120	M1	1	1	2

Comparative data from Garland et al. (2016) are included in Table 5. The two sites utilized in their study, La Capilla del Nino Serranito (CNS) and La Capilla Santa Maria Magdalena de Eten (CSMME), date from Early (1533-1624 CE) and Late (1625-1775 CE) Colonial era sites in the Lambayeque Valley Complex. The type of samples utilized by Garland et al. were different than those available for this study, namely their samples were all first molars, while this study used a combination of first and second molars and premolars. Garland et al. were also able to gather samples from individuals spanning a range

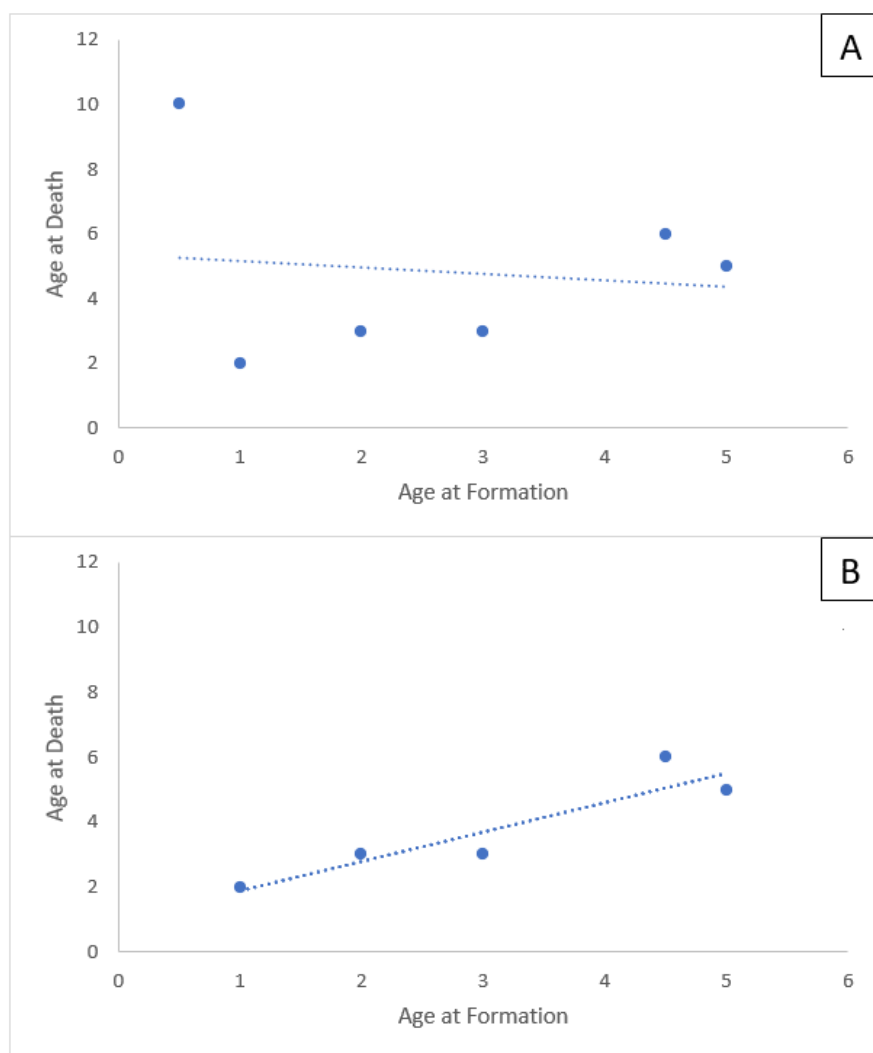


Figure 4: The age a Wilson band(s) formed compared to known individual's age-at-death including the outlier (A) and without the outlier (B). There is no strong association between age-at-death and Wilson band formation in A ($R^2=0.0154$). In B, a strong association exists between the two variables ($R^2=0.843$). The regression formula was $y = 0.9018x + 1.0045$.

of ages, while this study primarily used children or unaged individuals. Both studies relied upon teeth that did not exhibit significant grinding. Mann-Whitney U tests were conducted to compare the mean number of Wilson bands of the combined cohort and Late Moche cohort to CNS and CSMME, as both Colonial cohorts had a greater average number of Wilson bands per person than those from this study. None of the tests indicate statistically significant association (combined cohort vs CNS/CSSME, $p=0.334/0.784$, Late Moche vs CNS/CSSME, $p=0.789/0.333$).

Utilizing data from both the pre-Hispanic and Colonial samples, a Mann-Whitney U test was performed to determine if average age-at-death significantly differed across all north coast populations depending on the presence or absence of Wilson bands (Figure 5). Age-at-death did significantly differ between those who had a Wilson band and those who did not ($p<0.002$). A Kruskal-Wallis H-test comparing age-at-death between the pre-Hispanic and CNS/CSMME cohorts was also significant ($p=0.028$). Additional Mann-Whitney U tests were conducted between each group and significance was found between the Formative and Late Moche cohorts ($p=0.039$), the Formative and CSMME cohorts ($p=0.043$), and the CNS and CSMME cohorts ($p=0.05$). The Late Moche and CNS cohorts were approaching significance ($p=0.056$). As the Formative cohort only contained two individuals, future studies are needed to confirm this pattern and it will not be discussed further. The extremely limited number of aged pre-Hispanic individuals without a Wilson band was so small that no tests examining differences in age-at-death between the different cultural groups based on the presence or absence of Wilson bands could be conducted.

Table 5: Comparative statistics between Garland et al. (2016) and this study. The columns CNS (La Capilla del Nino Serranito) and CSMME (La Capilla Santa Maria Magdalena de Eten) are respectively Early and Middle/Late Colonial from Garland et al., while the Pre-Hispanic and Moche columns come from this study.

	CNS	CSMME	Pre-Hispanic	Late Moche
Total Individuals	15	15	14	11
No. w/Wb	11	8	10	10
% w/Wb	73.3	53.3	71.4	90.9
Mean No. of Wb	2.81	2.38	1.2	1.5

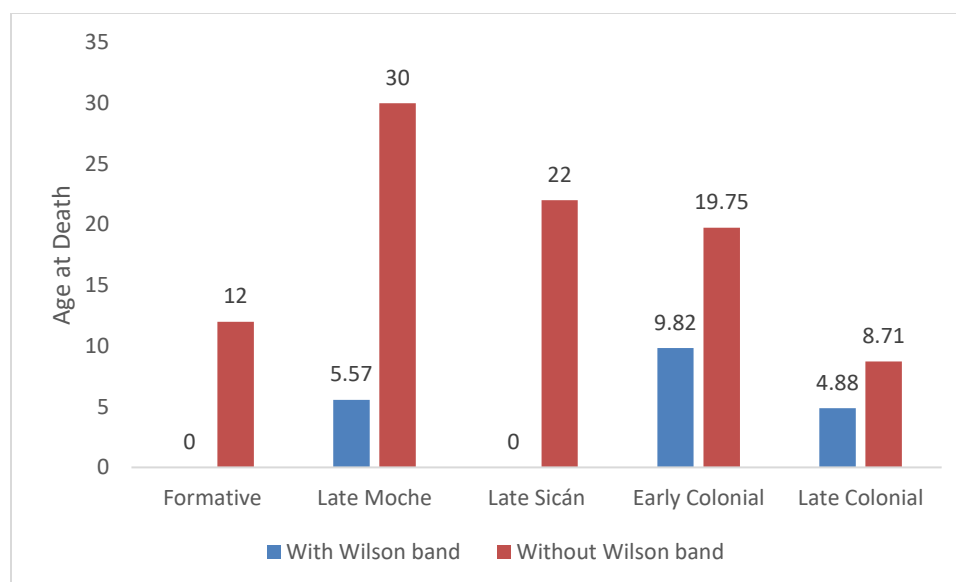


Figure 5: Average age-at-death for the different cohorts from this study and Garland et al. (2016). Age-at-death is further broken down by the presence or absence of Wilson bands.

Oxygen isotope values are reflective of the water consumed by an individual. Ratios are determined by evaporation, which in turn reflects the altitude, latitude, seasonal rainfall, and cooking practices (Balasse, Ambrose, Smith, & Rpiice, 2002; Chenery, Mueldner, Evans, Eckardt, & Lewis, 2010). As such, individuals living in different places are expected to have different oxygen signatures. Oxygen values derived from enamel are representative of the location that they grew up in. Prior to the cessation of weaning, children's oxygen isotope values are reflective of maternal body water. When comparing various individuals together, those who grew up in a nearby vicinity will display similar values, while those who grew up elsewhere will appear as outsiders. In addition, as boiling water can disproportionately discriminate against smaller isotopes of oxygen, individuals who primarily consumed boiled (and presumably cleaner) water will display higher values. Data from Turner & Klaus (2020) were included and compared to frequency of Wilson band per cohort (Figure 6A) in order to determine if the presence of Wilson bands was correlated with oxygen isotopic data. While one of the Formative individuals has elevated oxygen values, the rest of the population had relatively similar values.

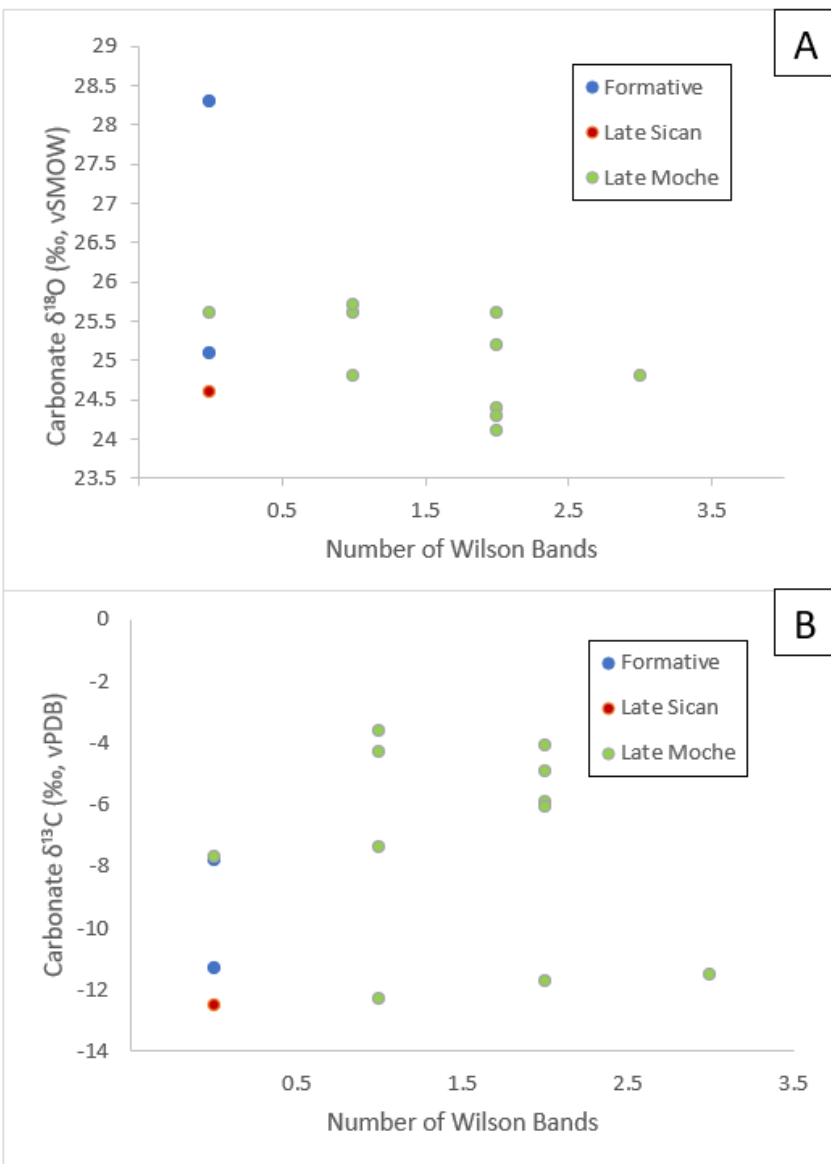


Figure 6: Scatterplot of Wilson band frequency and oxygen (A) and carbon (B) isotopic data. Oxygen and carbon isotopic data from Turner & Klaus (2020). 6A has a correlation coefficient of 0.2223 and 6B a correlation coefficient of 0.0313.

Using carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotopic ratios from collagen and for carbon, carbonate (CaCO_3), a generalized diet can be understood for an individual. However, only carbon values from enamel carbonate were present for the individuals examined in this study. Carbon isotope values are dependent upon the photosynthetic pathways of plants, such that C_4 plants discriminate against ^{13}C more than C_3 plants. As such, C_3 plants have smaller carbon ratios than C_4 plants; values are negative because they are

expressed relative to an established geological standard (Kohn, 2010; Von Caemmerer, Ghannoum, Pengelly, & Cousins, 2014). When an organism consumes a plant, the carbon isotope ratios are again fractionated,

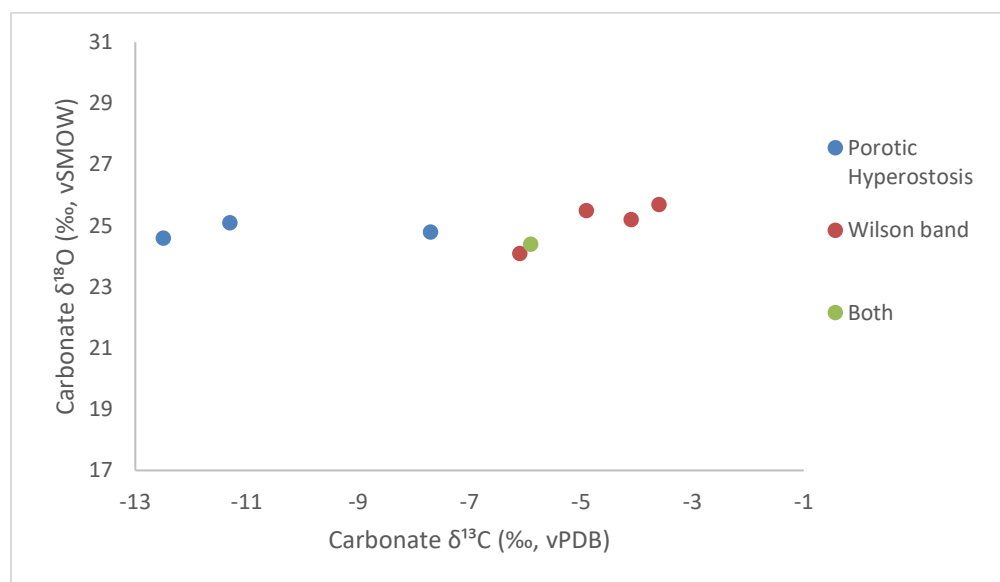


Figure 7: Carbon vs oxygen enamel carbonate data for those displaying only Wilson bands, those displaying only porotic hyperostosis, and those displaying both.

and the organism will display slightly higher carbon isotope values than the plant they consumed. This pattern continues as one travels up the food chain, such that consumers have the highest tissue $\delta^{13}\text{C}$ values. Carbon isotope ratios in enamel carbonate represents the dietary carbon utilized for energy from carbohydrates, fats, and proteins from marine and terrestrial plants and animals (Ambrose & Norr, 1993). Data from Turner & Klaus (2020) were included and compared to Wilson band frequencies per cohort (Figure 6B) to determine if diet varied depending on the presence or absence of Wilson bands. Carbon isotope values tended to be higher for those exhibiting at least one Wilson band. Those with elevated carbon values may have been consuming more C_4 plants such as maize, more marine foods, or more terrestrial animals who themselves were consuming C_4 plants.

Carbon and oxygen isotope data from Turner & Klaus (2020) were also plotted for those who had complete data regarding Wilson band and porotic hyperostosis presence (Figure 7). Those with

Wilson bands had higher carbon isotope ratios than those with porotic hyperostosis, and the singular individual displaying both lesions was in the middle for carbon values. Oxygen isotope ratios between the three groups is within what would be expected for the range of water sources at a given site (Turner, 2021), and do not indicate variation in environments during early life.

6.2 Discussion

6.2.1 Phenotypic Plasticity

The results of this analysis support a model of phenotypic plasticity, the concept that a stressful event in early life will encourage the body to invest in phenotypes that promote short-term survival at the expense of long-term survival (Temple, 2019; Worthman & Kuzara, 2005). Of the individuals with estimated ages-at-death (n=10), all individuals who had at least one Wilson band (n=7) died before the age of 12, while anyone without a Wilson band (n=3) made it to 12 or above before dying. Although the severe diarrhea caused by gastrointestinal infections (often associated with the formation of Wilson bands) is often thought of as a result of the infection, they may also be seen as the body expelling a foreign pathogen. Put otherwise, diarrhea may be seen as a phenotype associated with early life survival.

All of the stress events that caused the Wilson bands occurred at or before the age of 5. Because all of those who perished before the age of 12 had a Wilson band present, they must have survived long enough to overcome the original stressor only to perish a short time later, usually within a year of the stress event (Figure 3). Despite experiencing two stress events at 6 months and 7 months, Individual 74 from El Arenal did not die until age 10 and serves as an outlier (Figure 4A). However, sampling bias may be responsible for this discrepancy. The crown of the first molar, which was sampled for this individual, stops forming around three years of age. Had another tooth actively forming or recently formed around time of death been sampled, this individual may well have conformed to the observed pattern. It should

also be considered that the first molar sampled from this individual typically captures events associated with weaning. Because the stress events occurred at 6 and 7 months, the individual was likely still breastfeeding and receiving antibodies from their mother, which may have buffered them enough to survive (Kendall et al., 2021). As only one other individual with a known age-at-death had an M1 sampled, it could be that the other aged individuals would also demonstrate a similar pattern of survival. However, excluding this individual leads to a strong correlation between age-at-death and age at Wilson band formation ($R^2=0.84$). While this sample is too small for more analyses and needs additional data to confirm, the results do suggest that an early life stress event prior to the age of 5 generated elevated frailty associated with a significantly shortened lifespan.

This pattern holds true for not just pre-Hispanic populations analyzed in this study, but for all individuals from the Lambayeque region sampled to date. A combined cohort of this study's pre-Hispanic individuals and the Early and Middle/Late Colonial populations in Garland et al. (2016) showed significant differences between age-at-death for those who displayed at least one Wilson band and those who displayed none when a Mann-Whitney U test was performed ($p=0.02$). Thus, regardless of environmental or political conditions, frailty associated with early life stress results in an earlier age of death.

Although a lack of a Wilson band is associated with a later mortality date and longer lifespans, those without Wilson bands still died at a relatively early age. The oldest average age-at death for cohorts containing two or more individuals is from the Early Colonial era at 19.75 years. The young age-at-death is certainly in part due to the sampling design employed in both studies, in which only teeth without significant wear were selected. The older an individual is, the more ground down their teeth become and the more likely that any enamel microdefects would be obliterated. In addition, at least one of the internment sites utilized in this study, El Arenal, had a disproportionately high number of child burials, likely representing a range of cultural filters as opposed to being representative of the

population demographics. However, as seen in Table 2, pre-Hispanic individuals who did not have a Wilson band tended to have porotic hyperostosis, an indicator of chronic anemia. Anemia on the north coast has most often been attributed to bacterial infections, the inhibition of iron absorption as a result of diets high in phosphates (commonly found in marine foods), a deficiency in vitamins B9 and B12, and hemolytic and megaloblastic anemias (Blom et al., 2005; Klaus, 2020; Klaus & Tam, 2009). In pre-Hispanic individuals at least, the presence of either Wilson bands (representing acute episodic stress) or porotic hyperostosis (representing chronic stress) may reflect the different lived experiences and responses to a single stress event or stressful environment, to be discussed further under the osteobiographical account of pre-Hispanic life.

6.2.2 Comparison with Garland et al. (2016)

Although the CNS and CSMME cohorts studied by Garland et al. (2016) had higher average frequencies of Wilson bands, there was not a significant difference between the mean number of Wilson bands at either site when compared to the total pre-Hispanic cohort nor when compared solely to the Late Moche cohort using a Mann-Whitney U test. The insignificance with the Late Moche cohort suggests that children were facing similar levels of stress as that experienced in the Colonial era. Indeed, although the sample is smaller for Late Moche individuals, 90% of Late Moche individuals had at least one Wilson band while only 73% and 53% of the Early and Middle/Late Colonial cohorts respectively had Wilson bands. These results, although not significant, suggests that the Late Moche were more likely to encounter early life stressors, but either died before additional stress could be experienced (making them frailer) or were able to adapt to experience less stress moving forward, resulting in fewer Wilson bands.

Garland et al. (2016) associated Wilson band formation with limited and contaminated water sources related to living in overcrowded and unsanitary *reducciones*. These contaminated sources likely

then caused diarrheal diseases in infants when used in weaning foods. The Late Moche period may well have also struggled with contaminated water, especially at the beginning and end of the period due to the ENSO cycle of drought and flood (Dillehay & Kolata, 2004; Shimada, 1994b; Swenson, 2007). In addition, the individuals utilized in this study were likely of lower status (Alva Meneses, 2012) and thus had differential access to resources and increased stress exposure. Higher affliction rate coupled with lower average frequency rates suggests that the Late Moche were extremely susceptible to disease causing bacteria; indeed, the majority (5/7) of individuals who formed a Wilson band died within a year of its formation (Table 3). Garland et al. (2016) only utilized first molars in their study, which only capture the first three years of life. As such, it is not clear if a similar pattern of death after Wilson band related stress is true for Colonial individuals who died after the age of 4.

There was almost a statistically significant difference in age-at-death between Late Moche (5.57 years) and Early Colonial (9.82 years) individuals with at least one Wilson band when utilizing a Mann-Whitney U test ($p=0.056$). On the surface, it appears that Late Moche individuals were frailer and more likely to die from early life stress events. However, populations with a high birth rate and female fertility have larger numbers of infant deaths (Buikstra, Konigsberg, & Bullington, 1986). Unfortunately, it is not currently possible to determine the fertility levels at Ventarrón for the Late Moche cohort, so this possibility cannot be further examined. Due to the extremely small sample size of Late Moche and combined pre-Hispanic cohorts who did not have a Wilson band, age-at-death for pre-Hispanic populations without Wilson bands cannot be compared in a similar fashion to the Colonial cohorts.

This study only had three first molars with Wilson bands with which to compare to Garland et al. (2016). Each band formed at least halfway through the individuals first year at 6 months and 7 months for one individual and 10 months and 12 months for the other two. Garland et al. found similar results, with band formation peaking between 4-6 months and 10-12 months. The authors interpreted this as the beginning of weaning (likely supplemental), a common explanation in bioarchaeological literature as

bacteria in water and weaning foods can cause diarrheal diseases, which result in Wilson bands (FitzGerald et al., 2006; Katzenberg et al., 1996). However, Kendall et al. (2021) argue that breastmilk should maintain its protective buffering against infectious agents throughout the weaning process, especially when mothers are consuming the same contaminated water as their children. Might these ages then represent the beginning of crawling, walking, and teething, when infants begin moving about and putting potentially infectious materials in their mouths, especially as it would take longer for mothers to develop antibodies since they are not also actively consuming the bacteria?

None of the three individuals from the non-Moche samples from the Formative and Sicán periods displayed a Wilson band, and none of them died prior to the age of 12. With so few individuals, it is hard to make any definitive statements regarding other pre-Hispanic cultures compared to the Colonial population; however, the data do suggest individuals living under these cultures were not exposed to as many stressors as the Late Moche or Colonial populations, or were at least better at adapting to these insults. Future studies focusing on these and other early life stressors amongst a variety of pre-Hispanic cultures will provide a more nuanced understanding of life before the arrival of the Spanish, which in turn will provide a better understanding for how the Spanish did or did not change life on the north coast.

6.2.3 *Osteobiographical Account of pre-Hispanic Life on the North Coast*

Although the term pre-Hispanic has been used frequently throughout this thesis, the term itself covers a vast array of cultures, languages, political systems, world views, and more functioning under changing environments and landscapes. Some traditions such as that of the *parcialidad* system appear as a thread that carries on throughout time (Netherly, 1990). Others, such as the quipu knots, only appear in certain cultures (Urton & Chu, 2015). This section aims to highlight to the diverse lifestyles that have characterized the north coast and understand how different cultures interacted with and were

impacted by the outside world. Due to the small sample size stemming from only one site, this section will not make broad generalizations about the life experiences of others who resided in other locations. Instead, the life experiences of 14 people will be highlighted and understood through the lens of the cultures and times that they resided in.

The Formative sample (1000-400 BCE) contained two individuals, neither of which presented a Wilson band. The lack of a Wilson band on either of their second molars indicates that neither experienced an acute episodic stress event between the approximate ages of 3.5 to 6 years of age, and as such the cessation of weaning had already likely occurred. The lack of Wilson bands also suggests that Formative individuals at Ventarrón had access to clean drinking water that was not contaminated with bacteria. Although social inequality was beginning to occur during this time, evidenced by settlement hierarchies and interment patterns along the north coast and at Ventarrón (Alva Meneses, 2012; Elera, 1998), this admittedly small data sample suggests that differential access to resources and exposure to disease was not prevalent. During the Formative period, maize was only marginally consumed and people still relied heavily on a diverse range of resources provided by the local environment (Lambert et al., 2012; Washburn et al., 2020). This diverse harvesting and consumption of resources may have buffered the Formative individuals from experiencing acute stress.

The Late Sicán individual also did not present any Wilson bands. Like the Formative individuals, the tooth sectioned for the Sicán individual was a second molar, meaning that it is unlikely that either weaning or gastrointestinal infections occurred between the ages of 3.5 and 6. This individual did exhibit porotic hyperostosis, pointing to chronic anemia during their childhood. Because this cohort is only comprised of one individual, very little can be said about the population from whence they came. It could be speculated that the relatively peaceful Late Sicán period created an environment where individuals of a lower socioeconomic standing had adequate access to nutritious foods and a decreased disease burden, but more studies are needed to explore this hypothesis.

The Late Moche cohort was larger than the Formative or Late Sicán, lending itself to more examination. Age at Wilson band formation varied at the site. Due to the sampling method of this project, different teeth representing different developmental windows were selected for each individual. As a result, the wide prevalence of second molars and premolars might skew the results to a later age-at-formation as teeth from these individuals representing an earlier developmental window were not also examined. However, with the possible exception of one individual described earlier, all others presenting at least one Wilson band died around a year after formation. Thus, even though parents could treat children long enough for the formation of a band, continued exposure to an acute episodic stressor, possibly an unclean water source, likely contributed to the children's deaths.

Around 90% of the population ($n=10/11$) displayed at least one Wilson band, with an average of 1.5 Wilson bands per person. This high percentage of individuals with a Wilson band suggests that acute stressors were prevalent in the environment that this sample comes from. In addition, the relatively high average number of Wilson bands suggests that these acute stressors were episodic and occurred multiple times over these individuals' lives. Future studies examining multiple teeth that cover a variety of developmental windows could provide a better understanding of how frequently these events occurred over the course of an entire childhood. One possible explanation for the prevalence and frequency of these acute stress events is the consumption of contaminated water. While those buried at Ventarrón grew up locally (Figure 6A) (Turner & Klaus, 2020), most are thought to have lived close by in the surrounding area, not within the urban setting itself (Alva Meneses, 2012). Although it is again speculation, runoff from irrigated fields into the canals containing soil, fecal (especially from *guano* or camelid dung), or waterborne pathogens could have resulted in the periodic acute stress events. In addition, the periodic flooding caused by the ENSO cycle would likely cause occasional damage to infrastructure and increase contact with disease-carrying organisms (such as rodents or insects), which could again facilitate the spread of infectious diseases (Huckleberry et al., 2012; Kiracofe & Marr, 2008).

However, such severe flooding did not occur regularly, and as such it is unlikely to be the cause of acute stress in most children.

Another possibility for the stress patterns observed is that they represent the lived experiences of individuals from a low socioeconomic status. Previous research focusing on socioeconomic class and stress exposure amongst the Moche has found that elites were much less likely to have been exposed to childhood stress, including linear enamel hypoplasias and porotic hyperostosis, than non-elites (Klaus, 2018a; Verano, 1997a, 1997b). However, there may be a temporal bias as most elite burials are from the Early or Middle Moche period, and the non-elite burials are more likely to come from the Late Moche period (Klaus, 2020). Similar patterns of stress exposure being dependent on socioeconomic class has been observed for the Middle Sicán as well (Klaus, Shimada, et al., 2017). While the domestic site that the Late Moche comes from has yet to be identified and excavated, previous research of the north coast suggests that they would have had different lived experiences than elite individuals. For instance, individuals at Huaca Sialupe in the La Leche Valley are argued to be from a lower socioeconomic class based upon the construction of their households (wattle and daub) and the low quality of the animal foods they were eating (Shimada & Montenegro, 2002). Although this site is from the Middle Sicán period, it highlights the differential access to resources that socioeconomic status had on those living in the Lambayeque Valley Complex.

At Ventarrón, the Late Moche individuals with Wilson bands tended to have higher carbon values than those without any Wilson bands, indicating a different diet than those without Wilson bands (Figure 6B). Although more isotopic research is needed to parse out exactly what these higher values indicate, for now the higher values may represent the consumption of increased C_4 plants (likely maize), marine animals or seaweed, or terrestrial animals foddering on C_4 plants. This difference may of course represent personal choice, with some households actively choosing to consume certain foods over others. However, it could also be a byproduct of resource accessibility based on socioeconomic standing,

whereby those with higher carbon values had differential access to certain foods and as such were more susceptible to acute nutritional and/or parasitic stressors.

Of particular interest is the relationship between acute stress and chronic stress at the site. While there are not data on porotic hyperostosis and cribra orbitalia for all of the individuals, for those with data (n=8) an interesting relationship between acute and chronic stressors exists. Including those from the Formative and Late Sicán period, all of the individuals who did not form a Wilson band instead had porotic hyperostosis (n=3). Only one individual who had at least one Wilson band also had porotic hyperostosis, while the other four with at least one Wilson band had no chronic lesions. These data may only be a byproduct of having a small sample size. They may also be more representative of temporal and cultural differences between the Late Moche and the Formative and Late Sicán samples as Wilson bands were only found amongst Late Moche individuals and most of those with porotic hyperostosis lesions were from the other two time periods. However, these results may also be indicative of heterogeneity in frailty when exposed to the same stress(ors), likely an infectious disease.

There are two possibilities surrounding this concept. The first is that those with Wilson bands were already frail and at risk prior to becoming affected by a stress event, as postulated by Armelagos et al. (2009). As a result, their bodies had to invest more heavily in early life survival, possibly by expelling an infection with severe diarrhea, at the expense of longevity resulting in early mortality. Those who were not initially frail were able to avoid investing in an acute response to the stressor. However, the persistence of this stressor resulted instead in a chronic manifestation, that of porotic hyperostosis. The difference in diet between those manifesting each lesion could support this theory. While more research needs to be done to better understand what the differences in diet might have been, it could be that those with Wilson bands had diets comprised largely of maize and were deficient in other nutrients. When exposed to the stressor, again likely an infectious disease, their bodies were ill-prepared to fight off the infection forcing them to invest more heavily in short-term survival. Those who were consuming

more C₃ plants and possibly having a more complete nutritional make-up did not have to invest so drastically in short term survival.

The second possibility is that these individuals were affected by one stressor that normally causes a chronic response. However, when exposed to multiple stressors at one time, the synergistic interaction generated an acute response that created frailty and early mortality (Singer & Clair, 2003). While a variety of disease combinations could be responsible for this synergistic interaction, the difference in diet could also represent this scenario. The high carbon values of those with Wilson bands could represent an increase in marine consumption. By eating more marine foods, these individuals would have likely been more exposed to parasites. When exposed to both a stress event and parasites, their bodies would have had to invest more heavily in early survival than those not exposed to the parasites.

One example that could represent the second possibility is that of bartonellosis infection. As there is still much research to be done in identifying the disease, not just at Ventarrón but across the Andes as a whole, the following is purely a speculative scenario meant to apply Andean context to theory. Bartonellosis is spread from the bite of a sand fly, although it is hypothesized that a rodent reservoir also exists (Ellis et al., 1999; Gray et al., 1990). It occurs in two phases: an acute phase that causes fever, headache, bone and muscle pain, malaise, and variable degrees of anemia, and a chronic phase that results in skin lesions (Chamberlin et al., 2002). However, in the northeastern highlands where the disease is endemic, those infected with the disease may only exhibit the acute or chronic phase, may only exhibit mild symptoms, or may be asymptomatic (Chamberlin et al., 2002; Ellis et al., 1999; Gray et al., 1990). It is entirely possible then that bartonellosis may cause porotic hyperostosis in some cases. Bartonellosis exposes the body to co-infection with other gastrointestinal diseases and is highly lethal in such conditions (Orf & Cunnington, 2015). Although both bartonellosis and gastrointestinal diseases can occur at any time, during periods of excessive rainfall, increased humidity,

and higher temperatures (such as those associated with an El Niño) rates of bartonellosis and gastrointestinal diseases skyrocket, especially amongst children under the age of five (Chamberlin et al., 2002). As such, it is likely that children, if not at Ventarrón than likely in the highlands, contracted bartonellosis not infrequently. Those who survived without co-infection might develop porotic hyperostosis if the anemia became chronic. However, those who did become co-infected with a gastrointestinal disease would likely develop a Wilson band (if they survived long enough) but die before they could develop porotic hyperostosis.

6.3 Concluding Remarks

Exposure to disease, potentially aided by diet, played an important role in weakening individuals in the Lambayeque valley, increasing their frailty and resulting in their early mortality. Even in the Colonial period, European diseases and contaminated water from the *reducciones* drove high infection and mortality rates with diet playing an aiding role (Garland et al., 2016; Klaus & Tam, 2009). The impact of disease on north coast populations is not to be underestimated. Of particular interest was the correlation between age-at-formation and age-at-death of the majority of individuals with Wilson bands. While it appears that most individuals died shortly after forming a Wilson band, it is unknown if they also experienced stress as infants. It is also unknown if the individual who formed Wilson bands as an infant also formed one shortly before dying. Because thin slicing teeth is a destructive process, only the minimum number of teeth necessary should be sampled for ethical reasons. However, future research examining patterns of acute episodic stress and its impact on mortality should consider using multiple teeth representing various stages of childhood for a more complete picture. In order to remain as non-invasive as possible, the teeth selected should be those already broken or previously utilized for destructive analyses.

The variability of Wilson band prevalence amongst the pre-Hispanic populations at Ventarrón showcases the limitations of lumping pre-Hispanic cultures under one monolithic umbrella. Although the small sample size for this study precludes broad generalizations, there seems to be an intriguing association between episodic stress frequency and a cultural period marked by climatic upheaval and sociopolitical instability. The high prevalence of Wilson bands during the Late Moche period, despite not being as severe as during the Colonial periods, suggests an increased vulnerability of populations to infectious, waterborne diseases potentially related socioeconomic status. Conversely, the lack of Wilson bands from the earlier Formative or subsequent Late Sicán periods—albeit among small sample sizes—suggests that either the causal stressors were lower in these periods, or that buffering against such stressors was more effective.

An underlying theme throughout all of these results is the impact of different types of stress and their downstream effects on the life course, especially differential frailty, and its impact on the lives of those in this study. Even before the arrival of the Spanish, the Andes had complex disease ecologies that would have variably impacted segments of the population (Darling & Donoghue, 2014). While inherent barriers exist to studying disease in ancient populations, namely the absence or non-specificity of skeletal lesions, opportunities to relate stress markers to regional disease contexts such as those explored here stand to improve our understandings of these processes in antiquity. This study has demonstrated that disease and frailty are linked; future research exploring diet, practices linked to disease exposure, and when possible, the diseases prevalent in the study area will greatly enhance our understanding of how and why frailty emerged in the Central Andes.

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