#### **RESEARCH ARTICLE**



### Stable isotope analysis of a pre-Hispanic Andean community: Reconstructing pre-Wari and Wari era diets in the hinterland of the Wari empire, Peru

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#### Abstract

**Objectives:** Stable carbon and nitrogen isotope analysis is used to reconstruct diet among a pre-Hispanic population from the Peruvian Andes to evaluate whether local foodways changed with Wari imperial influence in the region. This study also compares local diet to other Wari-era sites.

**Materials and methods:** Samples derive from the site of Beringa in Peru and correspond primarily to pre-Wari (200–600 CE) and Wari (600–1,000 CE). We examine stable carbon isotopes from enamel (n = 29) and bone apatite (n = 22), and stable carbon and nitrogen isotopes from bone collagen (n = 29), and we present stable carbon and nitrogen isotope data on archaeological and modern fauna (n = 37) and plants (n = 19) from the region.

**Results:** There were no significant differences in either  $\delta^{13}$ C or  $\delta^{15}$ N from the pre-Wari to Wari era, indicating that those measurable aspects of diet did not change with Wari influence. There were no sex-based differences among juveniles (as inferred from  $\delta^{13}$ C from enamel carbonates) nor among adults (based on  $\delta^{13}$ C and  $\delta^{15}$ N from adult bone collagen). Comparisons to other Wari era sites show that Beringa individuals exhibited significantly lower  $\delta^{13}$ C values, suggesting that they consumed significantly less maize, a socially valued food. Further, the Froehle et al. (2012) stable isotope model suggests that the majority of the Beringa individuals consumed more C<sub>3</sub> than C<sub>4</sub> plants, and dietary protein was derived primarily from terrestrial animals and some marine resources.

**Conclusions:** The similar diets from pre-Wari to Wari times hint at strong local dietary traditions and durable food trade networks during the period of Wari imperial influence. The presence of limited marine foods in the diet suggests a trade network with coastal groups or sojourns to the coast to gather marine resources.

#### KEYWORDS

Andes, bioarchaeology, foodways, imperialism, Majes Valley

### 1 | INTRODUCTION

Communities that live in hinterland areas of an empire may have life experiences quite distinct from their counterparts in the imperial heartland, yet some aspects of health and diet may have been similar across the imperial domain. Those similarities and differences in health, diet, exposure to violence, and corporal expressions of identity can reveal much about how imperial policies and practices may have differed from region to region. They can also illuminate how local groups may have created and sustained local traditions in the face of imperial influence, whether in terms of foodways, ritual practices, childrearing norms, or other behaviors. In this study, we use stable isotope analysis to reconstruct dietary practices of a population that lived in the southern periphery of an ancient Andean empire to evaluate how imperial influence in a region may contribute to changes in food access and diet. Those kinds of empirical data can reveal insights into the local, domestic economy and how it articulated with the larger political economy of the region by



**FIGURE 1** Map of Peru showing location of Beringa and other Wari sites, including those mentioned in the text. (Map courtesy of Abel Traslaviña, Spatial Analysis Research Laboratory, Vanderbilt University.)

showing, for example, local food production patterns and regional trade networks (Hastorf and D'altroy 2002).

We examine stable carbon isotope ratios from enamel and bone apatite and stable carbon and nitrogen isotope ratios from bone collagen to reconstruct childhood and adulthood diets at the site of Beringa in Majes Valley of southern Peru (Figure 1). The Beringa individuals date to the pre-Wari (200–600 CE) and early Wari (600–800 CE) eras. The temporal groups are compared to examine whether local diets changed during the time of Wari imperial influence in the valley. The dietary isotope data are also compared with previously published data from other Wari-era populations to evaluate dietary similarities and differences throughout various parts of the Wari domain.

### 2 | RECONSTRUCTING DIETS IN ANCIENT STATES

## 2.1 Diet and foodways shaped by the state and local communities

A study of diet among peoples who live in peripheral zones of empires is an important topic of inquiry for anthropological bioarchaeologists because it makes overt the connection between state and local policies and their cultural and biological impacts (Dietler, 2006; Hastorf, 1990), while also revealing cultural attitudes about food and foodways (Purcell, 2003). Food is much more than nutritional sustenance (Haaland, 2007); food can be used to mark gender (Hastorf, 1991; Hyder et al., 2005; Sørensen, 2000, pp. 1889-1890), social status (Cook and Glowacki, 2003; Haaland, 2012), political position (LeCount, 2001), or a phase in the life course. Food can also be used to curry favor within or between communities (Bray, 2003), function as an aphrodisiac (Hospodar, 2004), appease the gods, or be perceived as a god-like entity, as in the maize god cults of Mesoamerica (Freidel and Reilly, 2010). The foods that are available to a community-or to certain members in a community-reveal much about broader political networks and alliances (Cook and Glowacki, 2003). That is, the consumption patterns of particular individuals or subgroups do not simply hint at idiosyncratic taste preferences; those data can speak to larger issues regarding how that person (or group of people) articulated with, or were excluded from, larger social and political systems.

That larger premise guides the work presented here, as we investigate whether maize (Zea mays), a food of high social and political value, was consumed by all or some of the individuals interred at Beringa during pre-Wari and Wari times. We also examine how maize consumption varied from childhood to adulthood. Stable carbon isotope ratios are examined to document maize (or other carbon enriched foods) in the diet. We also use stable nitrogen isotope data to document whether Beringa individuals consumed marine foods, which is important in and of itself, for it provides insights into the nutritional potential of the Beringa diet. However, dietary isotope data can also disclose information on the socio-political structures of a community. For example, evidence for marine food consumption would suggest trade relations with coastal peoples or frequent sojourns to the coast to obtain marine foods. If the latter, those sojourns could have occurred in either friendly or hostile territories, a point to consider given that a third of the Beringa adults exhibit cranial trauma (Tung, 2007a).

An analysis of how dietary practices shift through time can also reveal whether there are other larger changes in social or political organization. For example, in the case study presented here, we query whether patterns of food consumption are similar from pre-Wari to early Wari times; if so, then this would suggest that Wari imperial influence in the region did little to alter food production and consumption practices. Those dietary data in conjunction with other bioarchaeological data then provide deeper insights into how archaic forms of imperialism may have contributed to changes in some aspects of community life (e.g., access to exotic trade goods or altered frequencies of violence), while other community practices, such as foodways, proved to be more durable.

### 2.2 Archaeological background

The site of Beringa is located in the Majes Valley in the Department of Arequipa in southern Peru (Figure 1). There are several pre-Wari and Wari era sites in the middle and lower Majes Valley, all of which have yielded Wari-influenced style architecture (Malpass, 2001) and/or Wari and Wari-influenced artifacts, including ceramics, textiles, and spindle whorls (Bedregal et al., 2015; Garcia Márquez and Bustamante Montoro, 1990; Jennings, Tung, Yépez Álvarez, Lucano, & Hurtado, 2015; Koontz, 2011; Owen, 2007; Tung, 2007b), as well as obsidian from Wari-controlled quarries and other obsidian quarries (Tripcevich, 2009).

Excavations at Beringa were directed by Tung and focused on recovering human remains from the mortuary area in Sector A (Figures 2 and 3) (Tung, 2003, 2007b). The site is located on the left-hand margin of the Majes River (part of the Colca-Majes-Camana river system), which dumps into the Pacific Ocean 73 km away. The site's western edge drops into the Majes River, the northern and southern ends are capped by steep quebradas, and the eastern side ramps up steeply to cliffs that eventually reach the Majes-Siguas pampa, a desert landscape with large sand dunes and alluvial flows (Figure 3). It would have been (and still is) a difficult site to access. (Our excavation team could only access the site with rafts, and later, with a custom-built foot-bridge that was constructed after water levels in the river had decreased.)

There is currently no evidence to suggest that the domestic and mortuary site of Beringa was under direct Wari control. Instead, Beringa falls within a regional sphere of Wari influence, as reflected in the material remains (Owen, 2007; Tung, 2007b) that likely stem from indirect rule and the movement of peoples bringing in new iconographic styles from the Wari heartland (Owen, 2010; Tung, 2012). All burials, the majority of which were commingled within and around cist tombs, were recovered from Sector A (Tung, 2007b). Five tomb types were documented at Beringa, described in detail elsewhere (Tung, 2007b). Four of the five tomb types were cist-style tombs lined with stones around the opening, resulting in good bone preservation of the skeletons and mummy bundles that were inside. The largest tomb was 1.4 m deep and 4.5 m in diameter; several dozen individuals were interred there. The other tombs typically had one individual in them. Disturbed human remains were also on the surface of the site, but those were not sampled for this stable isotope study. Sectors B and C are primarily domestic areas, and they were mapped but not excavated.

The entire Beringa mortuary population consists of at least 236 individuals, though many individuals are represented by only few skeletal elements because looting and commingling led to the degradation of many bones that were on the site surface. Based on juvenile and adult crania that are at least half complete, the MNI is 101, demonstrating that many of the burials were significantly disturbed (i.e., only 43% of the burials had a well-preserved cranium present). In this study, we report the stable isotope data from those archaeological human remains that have been dated to the Early Intermediate period (EIP) (pre-Wari), the Middle Horizon (MH) (Wari era), and one adult female associated with the Late Intermediate period (LIP) (post-Wari).



FIGURE 2 Map of mortuary sector at the site of Beringa (Sector A) and the location of excavation units



FIGURE 3 Google earth image of middle Majes Valley. Site of Beringa (Sector A) is in the white box. (Image date 3/08/2016.)

# 2.3 Chronology of Wari influence in the region and site chronology

Previous work at, and a series of AMS dates from, the sites of Beringa and Uraca in the Majes Valley indicate Wari influence there by the early seventh century CE (Scaffidi, Vang, & Tung, 2017; Tung, 2007b). At the Majes Valley site of La Real, Wari influence is apparent around the mid-seventh century CE (Jennings et al., 2015; Tung, 2007a). Further south in the Moquegua Valley, evidence for Wari colonial infrastructure is apparent at Cerro Baúl by the late 6th to early 7th centuries CE (Nash and Williams, 2004; Williams, 2002) and continues until approximately CE 1000. Smaller sites near Cerro Baúl, such as Cerro Mejia, also exhibit changes reflective of Wari's imperial influence at the frontier of their domain (Nash, 2011, 2016).

Beringa was used as a mortuary space in the EIP, the MH, and the first half of the LIP. This is evident based on ceramic and textile associations (Owen, 2007) and 17 radiocarbon dates. Previously, seven radiocarbon dates from textiles that were wrapped around mummy bundles and from wood in architectural features showed that the site was used in the first half of the MH (Wari era), about 600–850 CE and again (or maybe continuously) in the first half of the LIP (post-Wari), about 1025–1275 CE (Tung, 2007a). Ten new radiocarbon dates from human bone, which will be published elsewhere, substantiate the MH and early LIP use of the site and also show some burials dating to the EIP (pre-Wari era) (Tung, n.d.). The EIP burials were not directly commingled with the MH burials, but some of the chronologically distinct tombs are within the same walled areas.

In short, the 17 AMS dates (calibrated with Oxcal 4.3 using SHcal 13 at 2 sigma), as well as artifact associations, show that the burials

belong to one of three temporal periods: EIP (pre-Wari), MH (Wari), and early LIP (post-Wari). It appears that the site was continuously used as a mortuary space throughout those three chronological periods. It is unknown if the domestic spaces in Sectors B and C also date to all three temporal periods because no excavations were conducted there.

#### 2.4 | The Beringa menu

Excavations at Beringa uncovered a wide variety of potential faunal and botanical food sources, ranging from items that could be locally procured to resources that may have come from the Pacific coast or the Amazon. Faunal food items include terrestrial and marine animals, such as camelids (*Camelidae*), guinea pig (*Cavia porcellus*), river shrimp (*Cryphiops caementarius*), and mollusks (bivalves and gastropods) (Figure 4) (Gladwell, 2004). The faunal analysis revealed that among the dietary remains (bones, shells, otoliths), 32% came from marine shell, 10% from river shrimp (*C. caementarius*), and 8% from fish (faunal analysis could not determine if they were freshwater or marine fish). The other half of the edible fauna was represented by guinea pigs (*C. porcellus*) and camelids (*Camelidae*) (Gladwell, 2004). Only 14 bones from the order *Artiodactyla* (ungulates) and two fragments of deer antler (family *Cervidae*) were uncovered at Beringa, suggesting that deer was an uncommon food source.

Among the marine shell, the most common bivalves recovered from Beringa include the Mesodesmatidae and Mytilidae from the Pacific coast (Gladwell, 2002); the shells clearly served as a material for beads, and the mollusk meat also may have been consumed. The nitrogen isotope data will aid in clarifying aspects of the diet as it relates to

### <sup>6</sup> WILEY <sup>American Journal of PHYSICAL ANTHROPOLOGY</sup>



FIGURE 4 C. caementarius (river shrimp) and shells from Mesodesmatidae and Mytilidae from the Pacific coast; all recovered from the Beringa excavations

terrestrial versus marine food consumption, the latter of which will be particularly important in establishing the extent of trade networks that the Beringa community had with people in coastal regions.

Other animal remains for which it is unclear whether they were food sources or not include thousands of amphibian bones from the families *Leptodactyla* (frogs) and *Bufonidae* (toads). The venom from some of those species could have been used as a hallucinogen. Skeletal elements from the families *Canidae* (dogs) and *Felidae* (cats) were also recovered, but no cut marks were observed on any of those 108 bones, so it is unlikely that they were food sources. One Amazonian parrot skeleton was also recovered; its bright feathers were likely used as adornments on textiles (King, Delgado Pérez, & Metropolitan Museum of Art, 2012). Indeed, one of the mummy bundles recovered from Beringa had a textile shroud covered with yellow/orange and white feathers, and the neighboring site of La Real located a few kilometers downriver yielded several feather-covered textiles (Quequezana Lucano, Yepez ALvarez, & Lopez Hurtado, 2012) and at least a half dozen Amazonian parrots.

The plant remains excavated at Beringa include potential food items such as several species of squash (*Cucurbita* sp.) and beans (*Phaseolus* sp.), as well as *molle* (*Schinus molle*), maize (*Z. mays*), peanuts (*Arachis hypogea*), yucca (*Manihot esculenta*), camote (*Ipomoea batatas*), lucuma (*Pouteria lucuma*), and coca (*Erythroxlum coca*) (Tung, 2007b). These plant remains were often placed in burial bundles; for instance, maize kernels, corn cobs, bundles of yucca, and bags of peanuts and beans were sometimes placed in the tombs, but it is yet unclear whether those food items were reserved for burial offerings or whether they were a significant part of the Beringa diet.

Maize is of particular interest because it was a crop of great social and political importance, and it only grows in the lower-lying regions of the Andes (i.e., typically below 3,000 m.a.s.l., though this depends on local climatic conditions and anthropogenic alterations to the landscape). Maize could have been grown in the middle Majes Valley in pre-Hispanic times, as it is today, but it is unclear if maize was indeed locally produced and consumed. Importantly, maize was the only C<sub>4</sub> plant recovered from Beringa, so its presence in the Beringa diet will be detected by the stable carbon isotope analysis (the nitrogen isotope data will also help to clarify the role of maize, if for example, there are other carbon enriched foods, such as marine resources, in the diet).

#### 2.5 Dietary isotopes: Background

Stable isotope analyses of carbon and nitrogen in archaeological human remains have become a well-established method for inferring paleodiet, with a growing number of paleodietary applications in the Andes (see recent examples by Knudson, Torres-Rouff, & Stojanowski, 2015; Pestle, Torres-Rouff, & Hubbe, 2016: Samec, Morales, & Yacobaccio, 2014; Santana-Sagredo, Hubbe, & Uribe, 2015; Somerville et al., 2015; Szpak, Longstaffe, Millaire, & White, 2014; Turner, 2015; Webb, White, Van Uum, & Longstaffe, 2015). Briefly, stable isotope ratios of <sup>13</sup>C to  $^{12}$ C, expressed as  $\delta^{13}$ C, distinguish between plants with different photosynthetic pathways (Chisholm, Nelson, & Schwarcz, 1982; DeNiro and Epstein, 1978; Schoeninger and DeNiro, 1984; Walker and DeNiro, 1986). Plants that utilize the C<sub>3</sub> (Calvin-Benson) photosynthetic pathway have low  $\delta^{13}$ C values, ranging from -20% to -35%with an average value of -26.5% (Calvin and Benson, 1948). Most plants use this photosynthetic pathway, including foods such as legumes, nuts, and tubers that are commonly consumed in the Andes. In contrast, plants that utilize the C<sub>4</sub> (Hatch-Slack) photosynthetic pathway have higher  $\delta^{13}$ C values, ranging from -9% to -14% with an average value of -12.5% (Hatch, Slack, & Johnson, 1967; Hatch and Slack, 1966; Johnson and Hatch, 1968; Kortschak, Hartt, & Burr, 1965). The most commonly-consumed C<sub>4</sub> plant in the New World is maize (Z. mays); kiwicha (Amaranthus caudatus), another C<sub>4</sub> plant native to the Andes, may be another source of carbon enriched foods for pre-Hispanic populations, though there was no paleobotanical evidence for it at Beringa. Finally, cacti and succulents using the Crassulacean Acid Metabolism pathway can exhibit  $\delta^{13}$ C values between C<sub>3</sub> and C<sub>4</sub> values, but can overlap with C<sub>4</sub> values (Ranson and Thomas, 1960; Smith and Epstein, 1971; Ting, 1985). The carbon isotope values in plants will then be reflected in the tissues of animals that consume the plants. More specifically, the carbon isotope values in bone collagen or hair keratin largely reflects the carbon present in dietary protein sources, while the carbon isotope values in bone or enamel hydroxyapatite reflect the carbon sources in the whole diet (Ambrose and Norr, 1993; Jim, Ambrose, & Evershed, 2004; Kellner and Schoeninger, 2007).

Given the effects of fractionation, the stable carbon isotope ratios from carnivorous mammalian bone collagen will be approximately  $4_{00}^{\circ}$ - $5_{00}^{\circ}$  higher than the plant tissues, and from bone carbonates, it will be approximately  $10_{00}^{\circ}$  higher (Ambrose and Norr, 1993; Lee-Thorp, Sealy, & Van der Merwe, 1989; Tykot, 2004). Those fractionation effects are considered when comparing the  $\delta^{13}$ C obtained from archaeological samples to those obtained from the modern and archaeological plants from the Majes Valley.

Nitrogen isotope analysis is particularly helpful for identifying marine food consumption. Differences in stable isotope ratios of <sup>15</sup>N to <sup>14</sup>N in collagen, which are expressed as  $\delta^{15}N_{collagen}$ , can distinguish between the terrestrial and marine food contributions to the diet as well as trophic level (Minagawa and Wada, 1984; Schoeninger, DeNiro, & Tauber, 1983). In a given ecosystem,  $\delta^{15}N$  values increase approximately 3% -5% in each trophic level (Hedges and Reynard, 2007; Minagawa and Wada, 1984; Schoeninger and DeNiro, 1984). In addition, because marine plants exhibit higher  $\delta^{15}$ N values than terrestrial plants (Wada, 1980), and because marine trophic systems are generally longer than terrestrial systems, individuals who consume predominately marine products will exhibit higher  $\delta^{15}$ N values compared with individuals who consume largely terrestrial products (Schoeninger et al., 1983). However, environmental factors, such as aridity, can also impact  $\delta^{15}$ N values, with warmer, arid regions exhibiting higher  $\delta^{15}$ N values compared with cooler and wetter regions (Ambrose, 1991; Ambrose and Deniro, 1987). Nitrogen isotope values from modern marine samples from the Peruvian and Chilean coast have been published and are used as comparative data when inferring marine product consumption at Beringa (Marsteller, Zolotova, & Knudson, 2017; Tieszen, Iversen, & Matzner, 1992).

### 3 | MATERIALS AND METHODS

Opportunistic sampling of the skeletal individuals was performed for biogeochemical research because the human remains were often commingled within each tomb area. As such, we selected samples from either discrete burials, from duplicating elements (if burials were commingled in a tomb), or from distinct tombs to ensure that an individual was not mistakenly represented multiple times in the sample. When possible, samples were collected from several dental and skeletal elements

#### American Journal of PHYSICAL ANTHROPOLOGY

from one skeleton to identify changes in diet over an individual's lifetime. The carbon isotope ratios from dental enamel that formed during different phases of the juvenile years are reported following Turner, Kamenov, Kingston, and Armelagos categorizations (2009): permanent incisors and first molars represent infancy and early childhood (IEC); permanent canines, premolars, and second molars represent middle childhood (MC), and the permanent third molars represent early adolescence.

The samples for which we have stable isotope data represent 26 individuals: approximately 26% of the Beringa population that was represented by a cranium (n = 101 crania). There are 29 bone collagen samples from 19 of the 26 individuals; 29 dental enamel carbonate samples representing 18 of the 26; 22 bone carbonate samples from 15 of them; 2 dentine samples from 2 of those 26 individuals; and 1 hair sample.

The EIP is represented by 14 individuals and the MH is represented by 11 individuals, though four of them do not have direct AMS dates so they could be late EIP. (Those four are labeled as EIP/MH in Table 3, and when statistical analyses are done to compare temporal groups they are initially excluded. We then added them into each temporal group (i.e., as part of the EIP subsample and then as part of the MH subsample) to evaluate whether any chronological differences are detected, discussed below). The LIP is represented by one individual and is not discussed in detail.

We also examined faunal and botanical samples to better contextualize the human dietary isotope data. Archaeological fauna from Beringa that underwent stable isotope analysis include two guinea pigs (*C. porcellus*) (one bone collagen and one fur sample), one dog (*Canis familiaris*), and the fur of nine camelids (*Camelidae*); one modern, local dog (*C. familiaris*) was also examined. Further, we present the carbon and nitrogen stable isotope data from 19 plant samples (16 modern plants from the Majes/Andamayo Valley and three plant samples from the nearby archaeological site of La Real). (See Tables 1 and 2 for details on samples.)<sup>1</sup>

All samples were exported from Peru and imported to the United States with appropriate permits from the Ministry of Culture in Peru and the U.S. Department of Agriculture.

# 3.1 | Methods used for carbon and nitrogen isotope analysis in collagen, keratin, and plant samples

Nitrogen and carbon isotope analysis of archaeological collagen ( $\delta^{15}N_{collagen}$ ,  $\delta^{13}C_{collagen}$ ) and keratin ( $\delta^{15}N_{keratin}$ ,  $\delta^{13}C_{keratin}$ ) was performed using the Thermo-Finnigan MAT 253 stable isotope ratio mass spectrometer in the W.M. Keck Foundation Laboratory for Environmental Biogeochemistry at Arizona State University. Sample preparation, including chemical cleaning, demineralization, and freeze-drying was performed in the Archaeological Chemistry Laboratory at Arizona State University according to established methods (Ambrose, 1990). Replicates of international standards resulted in a reproducibility of  $\pm 0.2\%$  for  $\delta^{15}N$  and

<sup>&</sup>lt;sup>1</sup>Although it would be ideal to include marine plants and marine resources in this study, limitations on funding and time prohibited this. Instead, we compared our data to published baseline data from the Peruvian and Chilean coasts.

American Journal of PHYSICAL ANTHROPOLOGY

<b>TABLE 1</b> Stable carbon and nitrogen isotope results from archaeological and modern plant sample	TABLE 1	Stable carbon and	l nitrogen isotope	e results from	archaeological and	modern plant sample
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Lab Code	Town/Site	Plant common name	Genus sp.	δ13C collagen (VPDB) (‰)	δ15N collagen(AIR) (‰)	%N	%C	C:N	Photosynthetic Pathway
1360	Pedregal	Coca leaf	Erythroxylum coca	-30.7	6.8	3.8	47.1	12.3	C3
1350	Pedregal	Cherimoya	Annona cherimola	-28.6	3.8	1.2	43.2	35.1	C3
1488	Pedregal	Black chuño	Solanum curtilobum	-27.9	3.7				C3
1353	Pedregal	Oca	Oxalis tuberosa	-27.7	4.6	0.9	40.9	46.2	C3
1352r	Pedregal	Yacon	Smallanthus sonchifolius	-27.4	5.2	0.7	42.8	60.4	C3
1355	Aplao	Lucuma	P. lucuma	-27.2	8.0	0.8	47.0	62.1	C3
1356	Pedregal	Papa salamanca	Solanum sp.	-26.9	1.1	1.0	40.4	41.3	C3
1349	Pedregal	Zapallo flesh	Cucurbita moschata	-26.9	1.9	0.7	41.1	55.2	C3
1357	Pedregal	Papa compes	Solanum sp.	-26.7	3.7	1.5	40.4	27.6	C3
1486	Andamayo	Wild molle leaves	S. molle	-26.2	7.5				C3
1362	Pedregal	Zapallo seed	Cucurbita moschata	-24.7	7.6	4.8	53.9	11.3	C3
1363	Andamayo	Wild molle seed	S. molle	-24.5	5.9	1.9	46.0	23.7	C3
1354	Pedregal	Maca	Lepidium meyenii	-23.9	7.4	1.7	41.6	24.6	C3
1351	Pedregal	Papa luisa	Solanum sp.	-23.6	4.1	1.9	40.6	21.8	C3
1069	La Real, structure 5	Frijoles (beans)	Phaseolus sp.	-23.1	0.2	3.8	41.4	11.0	C3
1361	Aplao	Molle seed	S. molle	-22.0	6.6	1.7	46.6	26.9	C3
1487	Pedregal	Kiwicha (amaranth)	A. caudatus	-13.2	3.1				C4
1070	La Real, C1-A	Outer tissues of corn cob	Z. mays	-11.4	11.8	1.9	39.8	20.5	C4
1071	La Real, C1-A	Internal tisses of corn cob	Z. mays	-11.0	10.9	2.0	42.4	20.7	C4

 $\pm 0.2\%$  for  $\delta^{13}$ C. The archaeological camelid fur and modern dog fur samples were analyzed in the Department of Earth and Planetary Sciences at the University of New Mexico using an elemental analyzer continuous flow isotope ratio mass spectrometer (Gladwell, Pacheco, Atudorei, & Tung, 2004). We follow recent work by Pestle, Crowley, and Weirauch (2014), and utilize the Minimum Meaningful Difference for interpreting collagen data, focusing on differences in  $\delta^{13}C_{collagen}$  that exceed 0.6‰ and on differences that exceed 0.9‰ for  $\delta^{15}N_{collagen}$  data.

Modern plant remains were collected from agricultural fields in the Majes Valley and from local markets in the town of Pedregal. The modern plant remains were oven dried at 60–70°C for at least four hours in the Bioarchaeology & Stable Isotope Laboratory at Vanderbilt University and nitrogen and carbon isotope analyses ( $\delta^{15}N$ ,  $\delta^{13}C$ ) of those samples were conducted at the University of Wyoming Stable Isotope Facility using a Costech 4010 Elemental Analyzer coupled to a Thermo Finnigan Delta Plus XP IRMS. Replicates of international standards resulted in a reproducibility of at least 0.15‰ for  $\delta^{13}C$  and at least 0.2‰ for  $\delta^{15}N$ .

For all sample types, the nitrogen and carbon isotope ratios are reported relative to the V-PDB (Vienna PeeDee belemnite) and AIR standards and are expressed in per mil (%) using standard delta notation (Coplen, 1994; Craig, 1961).

# 3.2 | Methods used for carbon isotope analysis in bone and enamel carbonate

Carbon isotope analysis of archaeological hydroxyapatite carbonate (δ<sup>13</sup>C<sub>carbonate</sub>) was performed using the Thermo-Finnigan Delta Plus Advantage stable isotope ratio mass spectrometer equipped with a GasBench interface in the W.M. Keck Foundation Laboratory for Environmental Biogeochemistry at Arizona State University. Sample preparation was performed in the Archaeological Chemistry Laboratory at Arizona State University according to established methods (Koch, Tuross, & Fogel, 1997b). Approximately 10 mg of tooth enamel powder or 15 mg of bone powder was treated with 0.40 mL of 2% NaOCI (bleach) and then 0.40 mL of 0.1 M CH<sub>3</sub>COOH (acetic acid); bone samples consisted of 15 mg of powdered bone with appropriately larger quantities of bleach and acetic acid. Long-term reproducibility of NBS-19 is  $\pm 0.04^{\circ}_{00}$  for  $\delta^{13}$ C. Carbon isotope ratios ( $\delta^{13}C_{carbonate}$ ) are reported relative to the V-PDB carbonate standard and are expressed in per mil (%) using standard delta notation (Coplen, 1994). Finally, following recent work by Pestle et al. (2014), we utilize the Minimum Meaningful Difference for interpreting carbonate data, focusing on differences in  $\delta^{13}C_{carbonate}$  that exceed 1.2%.

American Journal of PHYSICAL ANTHROPOLOGY MULLEY 9

 TABLE 2
 Stable carbon and nitrogen isotope results from archaeological and modern faunal samples

lastana lah sada	llait	Description	Matarial	δ13C collagen, keratin	$\delta$ 13C bone carbonate	δ15N collagen, keratin
	Unit	Description	Material			
0544-1	11	Camelid	Fur	-21.1		8
0544-2	11	Camelid	Fur	-21.1		8.2
0544-3	11	Camelid	Fur	-21.8		8.3
0545(DB)-1	11	Camelid	Fur	-21.8		7.7
0545(LB)-1	11	Camelid	Fur	-21.5		5.5
0545(LB)-2	11	Camelid	Fur	-21.2		5.8
0545(LB)-3	11	Camelid	Fur	-21		6.5
0545(MB)-1	11	Camelid	Fur	-19.6		8.9
0545(MB)-2	11	Camelid	Fur	-19.3		9.3
0546(DB)-1	11	Camelid	Fur	-22.1		9.2
0546(DB)-2	11	Camelid	Fur	-22.3		9
0546(LB)-1	11	Camelid	Fur	-21.9		8.4
0546(LB)-2	11	Camelid	Fur	-22		7.8
0546(MB)-1	11	Camelid	Fur	-20.5		8.1
0546(MB)-2	11	Camelid	Fur	-21		8.2
0546(MB)-3	11	Camelid	Fur	-21.1		8
0050-1	14	Camelid	Fur	-21		7.9
0050-2	14	Camelid	Fur	-20.7		8.5
0050-3	14	Camelid	Fur	-20.1		8.1
0053-1	14	Camelid	Fur	-20.5		7.4
0053-2	14	Camelid	Fur	-20.6		8.1
0061(DB)-1	18	Camelid	Fur	-15.4		7.9
0061(DB)-2	18	Camelid	Fur	-16.3		7.3
0090-1	23	Camelid	Fur	-19.5		9.1
0090-2	23	Camelid	Fur	-19.5		9.3
0090-3	23	Camelid	Fur	-17.9		10.5
0152-1	16N	Camelid	Fur	-20		7
0152-2	16N	Camelid	Fur	-20.2		6.9
0152-3	16N	Camelid	Fur	-20.4		7.2
0170(DB)-1	16N	Camelid	Fur	-20.5		8.4
0170(DB)-2	16N	Camelid	Fur	-19.7		8.4
0170(LB)-1	16N	Camelid	Fur	_18.6		0.1
0170(LB)-1	14N	Camelid	Fur	10.7		0
0170(LB)-2	141	Camelid	Fui	- 10.7		7
		Dog	Fur	10.1		10.2
	Аріао	Cuince air	Fur	-17.3	10.2	10.3
ACL-0247	16W	Guinea pig	Femur	-19.9	-10.3	5.8
ACL-0249	21	Dog	Tibia	-14.2	-10.8	9.9

TABLE 3 Stable carbon :	and nitrogen isotope	results f	rom the arch	aeological	human	samples fr	om Beringa							
Isotope lab no.	Bone code	Unit	Time period	Burial	Sex	Age (years)	Material	(B)one; (E)namel; (D)entine; (R)oot; (H)air	δ <sup>13</sup> C <sub>coll</sub> (VPDB) (‰)	δ <sup>13</sup> C <sub>carb</sub> (VPDB) (‰)	δ <sup>15</sup> Ν <sub>coll</sub> (AIR) (‱)	N%	%C	Z: C
ACL-2170	1001.0889	1	EIP <sup>a</sup>	5	<u>ر.</u>	10-12	Mx LP2	ш	NA	-10.5	NA	NA	NA	AN
ACL-0002	1001.1004.00	1	EIP <sup>a</sup>	31	<u>ر.</u>	1-3	Femur	В	-16.5	-16.3	11.5	13.9	34.4	2.9
ACL-0042	1001.1290.01	1	EIP <sup>a</sup>	A	ξ	40-45	Md RM2	E,D	NA	-10.6	9.0	9.5	NA	ΨN
ACL-0041	1001.1290.00	1	EIP <sup>a</sup>	A	Ω;	40-45	Mand	В	-14.4	-12.0	10.5	15.0	38.8	3.0
ACL-0043	1001.1293.02	1	EIP <sup>a</sup>	в	Σ	40-45	Md RM1	ш	NA	-9.8	NA	NA	NA	AN
ACL-2176	1001.0888	1	EIP <sup>a</sup>	U	<u>ر.</u>	6-8	Md RM1	Ш	NA	-11.4	NA	NA	NA	AN ANALA
ACL-0044	1001.1293.01	1	EIP <sup>a</sup>	D	Σ	30-35	Md RM3	E,D	-15.4	-9.5	8.1	10.9	28.0	
UCI-177551	1001.1295	1	EIP <sup>b</sup>	ш	<u>ر.</u>	7-9	Md LM1	Ж	-15.8	NA	9.5	15.7	44.2	3.3
ACL-0258	1001.1295	1	EIP <sup>b</sup>	ш	د.	7-9	Md LM1	Ш	NA	-10.9	NA	AN	NA	NA
UCI-177552	1001.0888	1	EIP <sup>b</sup>	ш	<u>ر</u> .	6-8	Md LM1	Ж	-15.6	NA	9.9	15.0	42.6	3.3
ACL-2174	1008.0031	8	EIP <sup>b</sup>	11	<u>ر.</u>	5-7	Mx LM1	Ш	NA	-8.1	NA	AN	NA	NA
UCI-177554	1008.0031	8	EIP <sup>b</sup>	11	<u>ر.</u>	5-7	Mx LM1	ĸ	-13.6	NA	10.2	15.5	43.9	3.3
ACL-2172	1008.0002	8	EIP/MH <sup>c</sup>	13	Ω;	15-34	Mx RM2	Ш	NA	-9.6	NA	NA	NA	AN
ACL-2173	1008.0029	œ	EIP/MH <sup>c</sup>	14	Σ	20-34	Mx RM3	Е	NA	-10.7	NA	ΑN	NA	NA
ACL-2171	1008.0004	8	EIP/MH <sup>c</sup>	17	ш	25-30	Mx RM2	ш	NA	-9.7	NA	ΝA	NA	NA
ACL-0036	1034.0026.00	œ	EIP/MH <sup>c</sup>	82	<u>ر.</u>	1-3	Femur	В	-14.8	-8.7	10.1	16.1	40.6	2.9
ACL-2175	1008.0017	œ	чHМ	U	ξ	20-40	Md RM1	ш	NA	-10.8	NA	NA	NA	AN
UCI-177555	1008.0017	00	чHМ	U	ξ	20-40	Md RM1	ч	-14.8	NA	10.8	15.2	43.0	3.3
ACL-0037	1011.0827.00	11	EIP <sup>b</sup>	92	Σ	35-49	Metatar3	В	-13.8	-12.3	11.1	11.1	38.8	3.0
ACL-0038	1011.0817.00	11	EIP <sup>b</sup>	92	Σ	35-49	Calcan	В	-14.6	-12.1	10.9	10.9	40.5	3.0
ACL-0039	1011.0802.00	11	EIP <sup>b</sup>	92	Σ	35-49	Rib	В	-13.8	-12.4	10.8	15.9	39.8	2.9
UCI-177549	1011.0802	11	EIP <sup>b</sup>	92	Σ	35-49	Rib	В	-13.9	NA	10.7	15.4	43.4	3.3
ACL-2169	1011	11	EIP <sup>a</sup>	т	۰.	20-49	Rib	В	-14.1	-11.6	10.9	17.3	43.2	3.0
ACL-0026	1102.0091.18.13	14	чHМ	66	<b>~·</b>	10-15	Md LM1	Ш	NA	-10.7	NA	ΝA	NA	NA
ACL-0027	1102.0091.18.14	14	чHМ	66	۰.	10-15	Md LM2	ш	NA	-11.2	NA	ΝA	NA	NA
ACL-0025 <sup>d</sup>	1102.0122.00	14	чHМ	66	<u>ر.</u>	10-15	Rib	В	-14.9	-10.9	10.1	10.1	40.6	3.0
UCI-177548 <sup>d</sup>	1102-0122	14	чHМ	66	۰.	10-15	Rib	В	-15.1	NA	9.8	15.6	44.6	3.3
													(Conti	nues)

TABLE 3 (Continued)														
Isotope lab no.	Bone code	Unit	Time period	Burial	Sex	Age (years)	Material	(B)one; (E)namel; (D)entine; (R)oot; (H)air	δ <sup>13</sup> C <sub>coll</sub> (VPDB) (‱)	δ <sup>13</sup> C <sub>carb</sub> (VPDB) ( <sup>%</sup> <sub>00</sub> )	δ <sup>15</sup> Ν <sub>coll</sub> (AIR) (%)	N%	%C	U S
ACL-0031	1134.0002.14	16	$MH^{a}$	71	ш	17-24	Md LM2	Е	NA	-9.6	NA	NA	NA	NA
ACL-0032	1134.0002.11	16	$MH^{a}$	71	ш	17-24	Md LI2	Е	NA	-9.0	NA	NA	NA	NA
ACL-0033	1134.0002.10	16	$MH^{a}$	71	ш	17-24	Md LC1	Е	NA	-8.9	NA	NA	NA	NA
ACL-0034	1134.0001.14.01	16	$MH^{a}$	71	ш	17-24	Mx LM3	Е	NA	-9.5	NA	NA	NA	NA
ACL-0029	1134.0023.00	16	$MH^{a}$	71	Ŀ	17-24	Rib	В	-13.5	-9.7	10.3	10.4	43.7	3.0
ACL-0030	1134.0052.00	16	$MH^{a}$	71	ш	17-24	Ulna	В	-13.5	-9.6	10.1	10.1	43.9	3.0
ACL-0003; UCI-183496	1017.0116.00	17	EIP <sup>b</sup>	55	<b>~·</b>	6-8	L Rib	В	-15.1	-11.0	11.0	14.1	35.3	2.9
ACL-0004	1017.0100.00.01	17	EIP <sup>b</sup>	55	د.	6-8	Md RM1	Е	NA	-8.5	NA	NA	NA	NA
ACL-0005	1017.0059.00	17	EIP <sup>b</sup>	56	Σ	35-49	Fibula	В	-15.3	-12.6	8.6	19.9	43.0	3.0
ACL-0006; UCI-183495	1017.0078.00	17	EIP <sup>b</sup>	56	Σ	35+	Rib	В	-16.4	-13.3	8.3	8.3	40.3	3.2
ACL-0007	1017.0050.14.05	17	EIP <sup>b</sup>	56	Σ	35-49	Mx LC1	Е	NA	-6.4	NA	NA	NA	NA
ACL-0008	1017.0050.14.01	17	EIP <sup>b</sup>	56	Σ	35-49	Mx LM2	Е	NA	-7.6	NA	NA	NA	NA
ACL-0009	1017.0051.	17	EIP <sup>b</sup>	56	Σ	35-49	Md LM3	Е	NA	-10.3	NA	AN	NA	NA
ACL-0012	1017.0024.00	17	EIP <sup>a</sup>	57	ш	35+	Rib	В	-14.5	-12.8	12.5	15.2	38.9	3.0
ACL-0013	1017.0044.00	17	EIP <sup>a</sup>	57	ш	35+	Metatar3	В	-14.9	-11.4	13.4	13.4	39.7	2.9
ACL-0010	1017.0039.15.07	17	EIP <sup>a</sup>	57	ш	35+	Mx RM3	Е	NA	-9.3	NA	NA	NA	NA
ACL-0011	1017.0039.15.05	17	EIP <sup>a</sup>	57	ш	35+	Mx RC1	Е	NA	-9.8	NA	NA	NA	NA
ACL-0020	1030.0032.00	19	$MH^{a}$	60	<u>ر.</u>	1-3	Rib	В	NA	-12.6	NA	NA	NA	AN
ACL-0019	1030.0040.00	19	$MH^{a}$	60	<u>ر.</u>	1-3	Femur	В	-15.1	-12.4	13.3	16.5	41.8	3.0
ACL-0021	1039.0018.04	23	LIP <sup>b</sup>	62	ш	35-49	Rib	В	-15.0	-10.5	10.5	16.8	43.2	3.0
ACL-0024	1039.0026.00	23	LIP <sup>b</sup>	62	ш	35-49	Femur	В	-14.1	-8.9	10.1	10.1	43.5	3.0
UCI-177553	1039.0002	23	LIP <sup>b</sup>	62	ш	35-49	Md LM2	R	-14.4	NA	9.6	15.6	44.2	3.3
ACL-0022	1039.0002.00.02	23	LIP <sup>b</sup>	62	ш	35-49	Md LM2	Е	NA	-7.9	NA	NA	ΝA	NA
ACL-0023	1039.0002.00.03	23	LIP <sup>b</sup>	62	ш	35-49	Md LM3	Е	NA	-7.2	NA	NA	NA	AN
ACL-2177	1039.0001	23	LIP <sup>b</sup>	62	ш	35-49	URM1	Е	NA	-7.4	NA	NA	NA	NA
ACL-0015	1025.0029.00	16N	чHМ	59	Σ	16-19	Rib	В	-13.6	-11.7	11.7	17.0	43.1	3.0
UCI-177550	1025.0002.01.10	16N	чHМ	59	Σ	16-19	Md LC1	К	-15.5	NA	10.1	14.8	41.4	3.3
													(Conti	nues)

American Journal of PHYSICAL ANTHROPOLOGY

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sotope ab no.	Bone code	Unit	Time period	Burial	Sex	Age (years)	Material	(B)one; (E)namel; (D)entine; (R)oot; (H)air	δ <sup>13</sup> C <sub>coll</sub> (VPDB) (‱)	δ <sup>13</sup> C <sub>carb</sub> (VPDB) (‰)	δ <sup>15</sup> Ν <sub>coll</sub> (AIR) (‰)	N%	%C	N.S.	
ACL-0018	1025.0002.01.10	16N	чHМ	59	Σ	16-19	Md LC1	Ш	NA	-9.9	NA	NA	NA	AN	Lŀ
ACL-0016	1025.0002.01.02	16N	чHМ	59	Σ	16-19	Md RM1	Ш	NA	-10.5	NA	AN	NA	AN	<u>-</u> Y
ACL-0017	1025.0002.01.01	16N	чHМ	59	Σ	16-19	Md RM2	Ш	NA	-10.6	NA	NA	NA	AN	А
ACL-0014	1025.0061	16N	чHМ	59	Σ	16-19	Hair	н	-14.7	NA	10.9	10.9	38.4	3.4	NTH Head Journal of the
ACL-0028	1103.0033.00	16W	$MH^{a}$	68	د.	1-3	L rib	В	-16	-13.4	10.9	15.5	39.7	3.0	ROP
ACL-0035	1147.0057.00	16W	мН <sup>а</sup>	73	د.	1-3	Femur	В	-16.7	-14.5	10.2	17.8	44.3	2.9	
Chronological association b	based on artifact assoc	iation and	d AMS dates	from the lc	cus and	/or unit.								aa ay aa ay aa ay ah ay ah	GY
Chronological association t	based on AMS dates di	irectly fro	om human bo	ne.											

EIP/MH samples are not included in the initial pre-Wari vs. Wari era comparison, but they are included in the analysis and discussion of Beringa diet as a whole.

<sup>1</sup>These two samples are from the same rib; stable isotope data from ACL-0025 only are used for calculating means and making statistical comparisons.

The raw data and descriptive statistics for the stable isotope ratios are presented in tables and graphs below. When comparing the stable isotope ratios between groups (e.g., time periods or different sites), a Student's *t*-test was performed when the two samples exhibited equal variances, otherwise a Mann Whitney U test was performed. The statistics were run using SPSS 24.

### 4 | RESULTS

### 4.1 Diagenesis

In order to remove diagenetic carbonates from enamel and bone samples, we used an acetic acid (CH<sub>3</sub>COOH) pretreatment step (Garvie-Lok, Varney, & Katzenberg, 2004; Koch, Tuross, & Fogel, 1997a; Lee-Thorp and Sponheimer, 2003; Lee-Thorp and van der Merwe, 1991; Nielsen-Marsh and Hedges, 2000; Yoder and Bartelink, 2010). Mechanical and chemical cleaning therefore minimized the presence of diagenetic contamination in these samples. Given the lack of a simple, predictive relationship between degree of diagenetic contamination and hydroxyapatite crystallinity, we did not use crystallinity indices to assess diagenesis (see discussions in Beasley, Bartelink, Taylor, & Miller, 2014; King, Tayles, & Gordon, 2011; Pucéat, Reynard, & Lécuyer, 2004; Trueman, Privat, & Field, 2008). We also used previouslypublished proxies for identifying diagenetic contamination; previously published studies have demonstrated biogenic elemental concentration and heavy isotope values from the same site and many of the same individuals (Knudson and Tung, 2011). This is particularly important since rare earth element concentrations in hydroxyapatite can reflect bone crystal-water interactions (Trueman et al., 2008). Given the exceptional bone preservation at Beringa, it is perhaps not surprising that there is little evidence of post-depositional contamination in bone or enamel hydroxyapatite.

Diagenesis of the collagen samples was assessed through atomic C:N values, following DeNiro (1985) and Ambrose (1993). In the archaeological human bone samples we analyzed, C:N values ranged from 2.9 to 3.3 and the mean C:N atomic ratio = 3.1 (n = 32). These are within the range of C:N = 2.9 to 3.6 that DeNiro (1985) specified as acceptable. Keratin samples analyzed exhibited C:N = 3.3–3.4, which is within the accepted range of C:N = 2.9–3.8 in modern hair (Coplen, 1994; O'Connell, Kneale, Tasevska, & Kuhnle, 2012). Further, the percent of the weight of preserved collagen from bone exceeds acceptable standards of at least 13% and 4.8% for carbon and nitrogen, respectively (Ambrose, 1990, p. 447) (see Tables 1–3).

# 4.2 | Archaeological and modern plants: The stable carbon and nitrogen isotope ratios

The plant samples exhibit  $\delta^{13}C$  that range from -30.7% to -11.0%, and as expected, there is a clear divide between the  $C_4$  plants with much higher  $\delta^{13}C$  values, relative to the  $C_3$  plants that exhibit very low  $\delta^{13}C$  values (Table 1 and Figure 5).

The  $\delta^{15}N$  from plants range from 0.2% to 11.8%, and they generally exhibit expected values. For example, the archaeological beans



**FIGURE 5** Carbon and nitrogen isotope values from modern and archaeological plants. 1.5% was added to all of the modern plant values to account for increased levels of carbon in the atmosphere in the modern era

(*Phaseolus* sp.) exhibit  $\delta^{15}N = 0.2_{00}^{\circ}$ , which is expected because legumes (their bacteria) fixate nitrogen directly from the soil. Nonetheless, we note that some of the plants in our sample may have come from fertilized fields, resulting in slightly higher than expected nitrogen isotope values.

## 4.3 Archaeological and modern fauna: The stable carbon and nitrogen isotope ratios

The one sample of archaeological guinea pig (*C. porcellus*) fur exhibits  $\delta^{13}C_{keratin} = -19.9\%$  and  $\delta^{13}C_{carbonate} = -10.6\%$ , and the one archaeological dog (*C. familiaris*) bone exhibits  $\delta^{13}C_{collagen} = -14.2\%$  and  $\delta^{13}C_{carbonate} = -10.78\%$ . Among the 34 archaeological camelid fur samples from nine camelids, mean  $\delta^{13}C_{keratin} = -20.2\%$  (*SD* = 1.6), and the values range from -22.3% to -15.4%. For the modern, local dog fur sample the  $\delta^{13}C_{keratin} = -19.3\%$  (see Table 2).

The nitrogen isotope values for the archaeological fauna are as follows: C. porcellus fur  $\delta^{15}N_{keratin} = 5.8\%$ ; C. familiaris bone  $\delta^{15}N_{collagen} = 9.9\%$ . Among the 34 camelid fur samples from nine camelids, the mean  $\delta^{15}N_{keratin} = 8.2\%$  (SD = 1.1), and the  $\delta^{15}N$  range from 5.5\% to 10.5\%. The modern, local dog fur exhibits  $\delta^{15}N_{keratin} = 10.3\%$  (see Table 2).

# 4.4 | Human enamel carbonate: The stable carbon isotope ratios

There are 29 dental enamel samples representing 18 individuals, and the  $\delta^{13}C_{\text{enamel carbonate}}$  ranged from -11.4% to -6.4%, and the mean  $\delta^{13}C_{\text{enamel carbonate}} = -9.5\%$  (SD = 1.3) (Table 3). The mean and SD for each chronological subgroup are presented in Table 4.

Among the dental enamel that forms in different phases of the juvenile years, the results were as follows: IEC mean  $\delta^{13}C_{enamel\ carbonate} =$  Anterican Journal of PHYSICAL ANTHROPOLOGY

 $-9.4_{00}^{\prime\prime}$  (SD = 1.5, n = 14); MC mean  $\delta^{13}C_{enamel carbonate} = -9.7_{00}^{\prime\prime}$  (SD = 1.2, n = 9); early teenage years (T) mean  $\delta^{13}C_{enamel carbonate} = -9.4_{00}^{\prime\prime}$  (SD = 1.2, n = 6). Although the differences between each age-development phase are not significant (U = 61.5, Z = .063, p = .952 and U = 19, Z = -0.884, p = .379, respectively), there is one male (Burial 56), one female (Burial 71), and one child (Burial 66) who all exhibit a decline in  $\delta^{13}C_{enamel carbonate}$  from the IEC tooth to the MC tooth, a pattern consistent with the effects of breastfeeding. The other intra-individual comparisons exhibited more subtle or random changes (see Table 3).

A box plot of the carbon isotope ratios for each age development phase shows a few outliers with higher  $\delta^{13}$ C (Figure 6). This is likely related to a more carbon enriched diet throughout childhood and not prolonged breastfeeding (i.e., the  $\delta^{13}$ C value for those outlier individuals was higher for all of their tooth types).

## 4.5 | Human bone carbonate: The stable carbon isotope ratios

The human bone carbonate mean  $\delta^{13}C = -11.9_{00}^{\circ}$  (SD = 1.8), and the range is  $-16.3_{00}^{\circ}$  to  $-8.7_{00}^{\circ}$  (n = 22 bone samples from 15 individuals). The mean carbon isotope ratios from bone carbonates for each temporal subgroup are presented in Table 4.

## 4.6 Collagen from humans: The stable carbon isotope ratios

The one human hair sample  $\delta^{13}C_{\text{keratin}} = -14.7_{\infty}^{\circ}$  and the two dentine samples yielded a mean  $\delta^{13}C_{\text{collagen}} = -14.5_{\infty}^{\circ}$  (*SD* = 1.3) (see Table 1 for individual values). All 29 human bone collagen samples exhibit a  $\delta^{13}C_{\text{collagen}}$  that range from  $-16.7_{\infty}^{\circ}$  to  $-13.5_{\infty}^{\circ}$ , and the mean  $\delta^{13}C_{\text{collagen}} = -14.8_{\infty}^{\circ}$  (*SD* = 0.9) (Figure 6). Among the adolescent and adult bone collagen samples, the mean  $\delta^{13}C_{\text{collagen}} = -14.5_{\infty}^{\circ}$  (*n* = 18), while the bone collagen from infants and children exhibited a mean  $\delta^{13}C_{\text{collagen}} = -15.4_{\infty}^{\circ}$  (*n* = 11), a difference that is significantly different (*t* = +3; *p* = .006; df = 27).

The mean bone collagen carbon isotope ratios for each time period are presented in Table 4, and the interpretations of those differences are discussed below.

# 4.7 | Collagen from humans: The stable nitrogen isotope ratios

The  $\delta^{15}N$  from the human bone collagen range from 8.3‰ to 13.4‰, and the mean  $\delta^{15}N = 10.6\%$  (*SD* = 1.1, *n* = 29 samples from 19 individuals) (Figure 6). The two dentine samples exhibit a mean  $\delta^{15}N = 8.6\%$  (*SD* = 0.6), and the human hair  $\delta^{15}N = 10.9\%$ .

The mean stable nitrogen isotope ratio for adolescents/adults and for infants/children is identical:  $\delta^{15}N = 10.6_{00}^{\circ}$ . This suggests that, at least as it relates to the consumption of similar trophic level protein foods; there were no significant changes in diet from childhood to adulthood.

The mean  $\delta^{15}$ N from bone collagen for each temporal phase are shown in Table 4 and discussed below (Figure 7).

Time period	Mean δ13C <sub>enam carbonate</sub> VPDB (‱)	Mean δ13C <sub>bone collagen</sub> VPDB (‰)	Mean δ13C <sub>bone carbonate</sub> VPDB (‰)	Mean $\Delta$ 13C <sub>carb-coll</sub>	Mean δ15N <sub>coll</sub> AIR (‰)
EIP	-9.4 (SD = 1.44, n = 13)	-14.8 (SD = 0.9, n = 15)	-12.5 (SD =1.4, n = 11)	2.3 (SD = 1.1, n = 11)	10.9 (SD = 1.4, n = 15)
EIP/MH	-10 (SD = 0.61, n = 3)	-14.8 (n = 1)	-8.7 (n = 1)	6.1 (n = 1)	10.1 ( <i>n</i> = 1)
MH	-10.1 (SD = 0.8, n = 10)	-14.9 (SD = 1.1, n = 10)	-11.9 (SD =1.7, n = 8)	3.0 (SD = 0.9, n = 7)	10.8 (SD = 1.4, n = 10)
Early LIP	-7.5 (SD = 0.4; n = 3)	-14.5 (SD = 0.5, n = 3)	-9.7 (SD =1.1, n = 2)	4.9 (SD = 0.4, n = 2)	10.1 (SD = 0.5, n = 3)
All	-9.5 (SD = 1.3, n = 29)	- 14.8 (SD = 0.9, n = 29)	-11.9 (SD =1.8, n = 22)	3.0 (SD = 1.4, n = 21)	10.5 (SD = 1.2, n = 31)

TABLE 4 The mean and SD of  $\delta^{13}C_{enamel carbonate}$  and  $\delta^{13}C_{bone carbonate}$  for human samples from each chronological subgroup at Beringa

### 5 DISCUSSION

An isotopic study of diet can clarify details about broader sociopolitical structures within a community and region, particularly as they relate to understanding how those forces shape food production, distribution, and consumption. As elaborated below, Wari influence in the southern hinterland had little to no impact on local childhood and adulthood diets at Beringa; the stable carbon and nitrogen isotope ratios from individuals at Beringa show dietary continuity from pre-Wari to Wari times. The results also show that the Beringa community had distinct dietary practices relative to Wari heartland communities and other Wari-era groups.

# 5.1 Dietary continuity through time: Maintaining local foodways in the Wari empire

The consumption of carbon enriched foods, such as maize, remained constant after the appearance of Wari influence in the Majes Valley. We infer this based on the non-significant difference in  $\delta^{13}C_{enamel\ carbonate}$  from the EIP (pre-Wari) to the MH (Wari) (U = 48.5; Z-score = 0.9923; p = .322). Additionally, the samples exhibit statistically similar  $\delta^{13}C_{bone\ carbonate}$  values (t = -0.94; df = 17; p = .36) and  $\delta^{13}C_{bone\ collagen}$  values (t = 0.05; p = .905; df = 23) between the pre-Wari and Wari eras.



**FIGURE 6** Box plot of the  $\delta^{13}C_{\text{enamel carbonate}}$  for the juvenile developmental phases. IEC, infancy-early childhood; MC, middle childhood; T, early teen

Moreover, the average differences in  $\delta^{13}$ C for all tissues between pre-Wari and Wari do not exceed the values expected in cases of profound dietary differences (i.e.,  $0.6_{00}^{\circ}$  for bone collagen and  $1.2_{00}^{\circ}$  for carbonates; Pestle et al. 2014). There was one bone collagen and three dental samples (representing four individuals) that could not be confidently assigned to either the EIP or the MH (labeled EIP/MH in Table 3), so those data are not included in the temporal comparisons above. Importantly, however, if the EIP/MH samples are placed in either temporal group, there are still no significant differences, further highlighting the similarity in stable carbon isotope values through time at Beringa.

These Beringa data mirror what Kellner and Schoeninger, (2008) observed among Nasca populations, where stable carbon isotope analysis showed that Nasca diets did not significantly change with the onset of Wari imperial influence in the region. However, the Beringa data are in contrast to the coastal Ancón population in northern Peru, where a study of stable carbon and nitrogen isotopes showed that Wari influence in the late MH corresponds to a decrease in the



**FIGURE 7** Stable carbon and nitrogen isotope values for human bone collagen, guinea pig and dog bone collagen, camelid fur samples from Beringa, and a fur sample from a modern dog at a village near the site. The raw isotope ratios are presented; note that collagen from keratin (fur) in animals tends to yield  $\delta^{13}$ C that is 2 to 4% less than animal bone

ingestion of marine resources and a possible increase in maize consumption (Slovak and Paytan 2011, pp. 259–261).<sup>2</sup>

The later dietary changes associated with the transition from Wari to post-Wari were difficult to assess because only one individual (an adult female with multiple tissues sampled) corresponds to post-Wari. Her mean  $\delta^{13}C_{enamel\ carbonate} = -7.5\%$  (n = 3 teeth), which is 2.5% higher than the Wari-era mean. Thus, this individual consumed more carbon enriched foods (likely maize) as a child relative to Wari-era children at Beringa, but we do not claim that she is representative of the post-Wari era population. The pattern is the same for the  $\delta^{13}$ C from bone carbonate and bone collagen (i.e., this one LIP individual shows a higher  $\delta^{13}$ C value for bone carbonate and bone collagen than the Wari era sample).

The stable nitrogen isotope data from bone collagen also reveal continuity in dietary protein through time (Table 3). There is no significant difference in  $\delta^{15}N_{\text{bone collagen}}$  from the pre-Wari to Wari era (t = -0.15; df = 23; p = .882), nor from the Wari to post-Wari era (t = 1.03; df = 11; p = .33). The mean  $\delta^{15}N_{\text{bone collagen}} = 10.5\%$  for all bone collagen samples suggests a diet of terrestrial, river (i.e., freshwater shrimp), and some marine protein. This interpretation is supported by the zooarchaeological data (Gladwell, 2002), the analysis of carbonate-collagen spacing, and comparisons to the carbon isotope model developed by Kellner and Schoeninger (2007) and Froehle, Kellner, and Schoeninger (2012), discussed below. The river shrimp likely yield  $\delta^{15}N$  similar to, though slightly higher than, the terrestrial herbivores (Miller, Capriles, & Hastorf, 2010; Schoeninger and DeNiro, 1984), but the relative proportions of river and marine resources is currently unknown. (Given the statistically similar  $\delta^{13}$ C and  $\delta^{15}$ N for all tissues, the entire Beringa sample (i.e., all time periods) is used when comparing Beringa to other Andean sites, discussed below.)

These stable isotope results show a pattern of dietary continuity from the pre-Wari to Wari transition. However, it is unclear if, on the one hand, dietary stability resulted from local efforts to challenge newly forming Wari influence in the valley and maintain native foodways. That is, Wari policies may have sought to alter food production and consumption patterns by people in the Majes Valley—as the later Inka empire had done in various areas throughout its domain (Hastorf, 2002)—only to see their policy efforts fail at the local level. On the other hand, Wari policies may have intentionally left indigenous food practices intact while focusing on other aspects of Beringa production capacities (e.g., demand for cotton production and textile goods and/or the collection of *S. molle* berries, which are abundant in the region).

#### 5.2 Similarities in diet between males and females

Although sex cannot be reliably estimated from juvenile skeletons, those who die as adults can typically be identified as male or female, and their  $\delta^{13}C_{\text{enamel carbonate}}$  can be compared to examine whether boys and girls consumed distinct diets in childhood. This kind of comparison aids in investigating whether there was sex-based differential

investment in offspring and/or childhood gender norms that shaped access to foods. For girls, the mean  $\delta^{13}C_{enamel\ carbonate}=-8.8\%$ (SD = 1.0, n = 10), and for boys the mean  $\delta^{13}C_{\text{enamel carbonate}} = -9.7\%$ (SD = 1.4, n = 12). These means are not significantly different (t = 1.68, n = 1.4)p = .11, n = 22, df = 20), though the distribution of  $\delta^{13}$ C for each sex is significantly different (U = 24.5, p < .05, Z-score = -2.31, p = .021), such that the childhood males show greater variance and the highest and lowest stable carbon isotope values. In short, the feeding patterns of infants and young children, as measured by average  $\delta^{13}$ C, do not appear to reflect a sex-based bias in (grand)parenting, nor are childhood diets strongly structured by biological sex. (Dietary differences between distinct performed gender identities are unknown at this time). The greater variance in boyhood diets relative to girlhood diets, and the overall absence of a mean difference in  $\delta^{13}$ C, may suggest that childhood consumption patterns were less influenced by gender, and more influenced by household food preferences, household access to resources, or children's idiosyncratic tastes.

Similar diets among boys and girls (as evidenced by  $\delta^{13}C_{enamel\ carbonate}$ ) were also documented at the Wari-era site of Ancón (Slovak and Paytan, 2011) and among post-Wari populations in the former Wari heartland (Tung, Miller, Santis, Sharp, & Kelly, 2016), leading Tung to suggest that childhood sex-based differences in diet at those sites may be rare because gender norms and gender roles may not have been fully recognized and actualized before puberty. As individuals become socialized into specific gender roles (and statuses associated with those gender roles), those differences may eventually translate into dissimilarities in diet, injury patterns, and other aspects of health, some of which may exhibit more sex-based distinctions than others.

At Beringa, the average sex-based similarities in diet continue into adulthood. Adult females (mean  $\delta^{13}C_{\text{bone collagen}} = -14.3\%$ ) and adult males (mean  $\delta^{13}C_{\text{bone collagen}} = -14.6\%$ ) exhibit statistically similar mean stable carbon isotope ratios whether all bone samples from each sexed individual are compared (t = 0.86, df = 15, p = .4) or the average value of multiple bone samples from each female and male are compared (t = 0.9, df = 5, p = .41).

The same pattern is observed for stable nitrogen isotope ratios (female mean  $\delta^{15}N_{\text{bone collagen}} = 10.9\%$  and male mean  $\delta^{15}N_{\text{bone collagen}} = 10.4\%$ ), whether comparing the multiple bone samples (t = 0.95, df = 15, *p* = .36) or the average value from each individual (*t* = 0.81, df = 5, *p* = .46). Granted, the sample sizes for sex-based comparisons among Beringa adults are small, but their similarities in diet parallel what has been observed among adults in the Nasca region (pre-Wari and Wari eras) (Kellner and Schoeninger, 2008) and at Ancón (early Wari and late Wari eras) (Slovak and Paytan, 2011).

# 5.3 | Increased maize consumption from childhood to adulthood

Intra-site comparisons of bone collagen means from those who died in infancy/childhood (mean  $\delta^{13}C_{bone\ collagen}=-15.4\%)$  relative to those who died as adolescents/adults (mean  $\delta^{13}C_{bone\ collagen}=-14.5\%)$  showed a significant difference (see above), indicating that the consumption of carbon enriched foods increased as one grew older. This

 $<sup>^2{\</sup>rm The}$  Ancón study documented the difference in the late MH only, whereas this study compares the EIP (pre-Wari) to samples belonging to the entire MH.

difference is not related to different childhood diets among those who ended up dying in childhood versus those who survived into adulthood, as supported by the statistically similar  $\delta^{13}C_{enamel \ carbonate}$  among those two groups (using IEC and MC teeth only because there were no third molars for the juveniles) (t = -1.57; p = .13; df = 21). That is, as children both groups ate similar diets (as it relates to what can be measured by  $\delta^{13}$ C), and then the diet appears to change as one moves into adulthood. This may be reflecting local cultural norms about how dietary practices change through the life course, hinting at a greater consumption of the socially valued food—maize—as one reaches puberty and advances into adulthood.

The carbon-enriched dietary change was not mirrored by changes in nitrogen-enriched foods as one grew older (mean  $\delta^{15}N$  for juveniles versus adults were identical, see above).

### 5.4 | Sources of dietary carbon

The source of the carbon in the Beringa diet can be estimated by examining the following: (a) differences between carbon isotope ratios in bone collagen and bone carbonates ( $\Delta^{13}C_{coll-carb}$ ) (Ambrose and Norr, 1993); (b) how the stable isotope data fit three regression lines that reflect C<sub>3</sub>, C<sub>4</sub>, and marine diet protein (Kellner and Schoeninger, 2007); and (c) how the stable isotope data fit the multivariate carbon and nitrogen stable isotope model (Froehle et al., 2012).

First, because bone collagen primarily reflects the protein source of the diet, while bone carbonates reflect whole diet, those can be compared to estimate whether the carbon enriched food source is protein-depleted (e.g., maize) or protein-rich (e.g., marine, and perhaps kiwicha) (Ambrose and Norr, 1993; Harrison and Katzenberg, 2003). In short, if the  $\Delta^{13}C_{coll-carb}$  is larger than 4.4%, then a diet of C<sub>4</sub> plants (e.g., maize) and C<sub>3</sub> protein (i.e., terrestrial animals) is suggested (Ambrose, Butler, Hanson, Hunter-Anderson, & Krueger, 1997). In contrast, if  $\delta^{13}C_{carb-coll}$  is <4.4\%, then a diet of C<sub>3</sub> carbohydrates (i.e., non-maize plants) and marine protein is suggested (Ambrose et al., 1997).

For pre-Wari and Wari times, the mean  $\Delta^{13}C_{carb-coll} = 3.3_{00}^{\circ}$  and  $3.0_{00}^{\circ}$ , respectively, values that tentatively suggest that Beringa inhabitants consumed primarily C<sub>3</sub> plants and carbon enriched foods that were high in protein (e.g., marine foods and/or kiwicha). The one female from the early LIP exhibits a mean  $\Delta^{13}C_{carb-coll} = 4.9_{00}^{\circ}$ , suggesting that her diet was more characterized by maize and terrestrial protein.

Second, the Kellner and Schoeninger (2007) model plots three regression lines based on known animal (pig, mouse, rat) diets and their  $\delta^{13}C_{carb}$  and  $\delta^{13}C_{coll}$ , a technique that aids in distinguishing between diets with C<sub>3</sub> versus C<sub>4</sub> protein. Application of this model supports the general interpretation that Beringa diets were characterized by high protein foods and C<sub>3</sub> energy food sources (i.e., C<sub>3</sub> lipids and carbohydrates). In other words, maize was not a staple food source for Beringa inhabitants; instead, the largest source of carbohydrates and fats come from C<sub>3</sub> plants and animals that also consumed C<sub>3</sub> plants. Dietary protein was likely sourced from carbon enriched foods that were high in protein (Figure 8). Given the abundance of marine shell at Beringa, marine foods are a possible source.



FIGURE 8 The Beringa  $\delta^{13}$ C bone carbonate and bone collagen data plotted against values for known diets from animal studies (Kellner and Schoeninger, 2007)

Third, the multivariate carbon and nitrogen stable isotope model (Froehle et al., 2012) reveals the relative contribution of marine vs. terrestrial protein. Beringa results show that a small group falls in Clusters 1 and 4, suggesting that their C<sub>3</sub> energy foods (e.g., lipids and carbohydrates) were 100%–70% C<sub>3</sub> foods, and protein sources were 65%– 100% C<sub>3</sub> derived (Figure 9). All other individuals fall between Clusters 2 and 4 (closer to Cluster 4), which suggests slightly more C<sub>3</sub> than C<sub>4</sub> energy foods (i.e., they ate more C<sub>3</sub> plants than C<sub>4</sub> plants). And although C<sub>4</sub>-derived proteins were still part of the diet (e.g., 35% to <50% of the protein component of the diet), the majority of their protein sources were more C<sub>3</sub> derived (see Froehle et al., 2012).

#### 5.5 Comparing the plants, animals, and humans

The stable carbon and nitrogen isotope ratios from modern and archaeological plants and animals support the interpretations about food sources for the Beringa population. Given fractionation effects in carnivorous mammals, the  $\delta^{13}C_{\text{bone carbonate}}$  was converted to more accurately reflect dietary carbon ( $1.04 \times \delta 13C_{\text{bone carbonate}} - 9.2\%$  [Ambrose and Norr, 1993]); thus, the mean bone carbonate  $\delta^{13}C_{\text{diet}} = -20.3\%$  (SD = 1.9) and range from  $\delta^{13}C_{\text{diet}} = -26.2\%$  to  $\delta^{13}C_{\text{diet}} = -15.9\%$ . The  $\delta^{13}C_{\text{collagen}}$  was also converted to  $\delta^{13}C_{\text{diet}} = -19.3\%$  (SD = 0.9) and a range of  $\delta^{13}C_{\text{diet}} = -21.2\%$  to  $\delta^{13}C_{\text{diet}} = -18\%$ . The  $C_3$  plants from in and around Majes Valley range from  $\delta^{13}C = -30.7\%$  to  $\delta^{13}C = -22\%$  to -11%. These direct comparisons undergird the notion that Beringa peoples consumed a diet dominated by  $C_3$  plants (with some  $C_4$  inputs) and animals that consumed  $C_3$  plants.

The  $\delta^{15}N_{collagen}$  was also converted to  $\delta^{15}N_{diet}$  by subtracting 3‰ from  $\delta^{15}N_{collagen}$ , a reasonable estimate based on various studies of  $\delta^{15}N$  diet-collagen differences (Ambrose, 2002; Bocherens and Drucker, 2003; DeNiro and Epstein, 1981; Hedges and Reynard, 2007; Schoeninger and DeNiro, 1984). After converting the bone collagen, the mean  $\delta^{15}N_{diet} = 7.6\%$  (SD = 1.1) and ranges from  $\delta^{15}N_{diet} = 5.3\%$ 



FIGURE 9 The Beringa  $\delta^{13}$ C bone carbonate and bone collagen and  $\delta^{15}$ N bone collagen data plotted on the multivariate carbon and nitrogen stable isotope model (Froehle et al., 2012)

to  $\delta^{15}N_{diet} = 10.4_{0o}^{\circ}$ . The bone collagen from archaeological guinea pig exhibits  $\delta^{15}N = 5.8_{0o}^{\circ}$ ; thus, while the Beringa population consumed terrestrial animals, there were likely some small contributions from marine resources too, as the Kellner and Schoeninger (2007) and the Froehle et al. (2012) models suggest.

The archaeological dog sample from Beringa shows that the  $\delta^{13}$ C and  $\delta^{15}$ N were nearly identical to that of the humans, suggesting that the dog had close proximity to humans and their food scraps. This hints at close relationships between people and dogs, not a predator–prey interaction, an interpretation that is supported by the mortuary data in which a partially intact dog burial was recovered from a tomb at Beringa. This is not uncommon in the pre-hispanic Andes, where dog burials have been found at various sites, such as Huaca el Rosal in Lima and Rio Muerte in Moquegua, and a Chirbaya site, also in Moquegua.

## 5.6 Less maize at Beringa than other Wari-affiliated sites

Given that the mean  $\delta^{13}C_{enamel \ carbonate} = -9.5\%_{oo}$  at Beringa, carbon enriched foods such as maize were not a primary staple in childhood diets. This is in contrast to the elite Wari heartland site of Conchopata (mean  $\delta^{13}C_{enamel \ carbonate} = -4.8\%_{oo}$ , n = 35) where C<sub>4</sub> consumption was significantly more common than Beringa (Mann-Whitney U, z = 5.76, p < .001). (At Conchopata, 19 carbon isotope ratios from enamel are from Finucane, Maita, and Isbell (2006) and the other 16 values are from Tung's unpublished data.) This mean difference of  $4.7\%_{oo}$  is remarkable, and the statistically significant difference overall suggests that Conchopata children in the imperial heartland had much greater access to the socially valued crop, maize, relative to those in the southern hinterland. (When the early LIP individual is removed from the Beringa sample, the difference is still significant.) This is extraordinary considering that Beringa is in a maize growing region, and Conchopata is near the altitudinal limits of maize production, an observation that hints at the success of Wari imperial statecraft in terms of producing and importing this politically powerful food that could aid in making and marking elite status.

Stable carbon isotope ratios from bone collagen at Beringa reveal a similar story: significantly less maize relative to those at the intermediate elite Wari heartland site of Conchopata (mean  $\delta^{13}C_{\text{bone collagen}} = -10.6\%$  [Finucane et al., 2006]) (t = -13.8; p < .0001; df = 48) and the heartland commoner site of Marayniyoq (mean  $\delta^{13}C_{\text{bone collagen}} = -9.7\%$  (Finucane, 2009) (t = 20.06; df = 95; p < .0001). Wari-era sites in other regions also show higher  $\delta^{13}C_{\text{bone collagen}}$ , as observed at the coastal site of Ancón ( $\delta^{13}C_{\text{bone collagen}} = -10.6\%$  [Slovak and Paytan, 2011]) (t = -16.85; p < .0001; df = 51). In the Las Trancas Valley of the Southern Nasca Region (Kellner and Schoeninger, 2008), those MH communities again show significantly more consumption of carbon enriched foods relative to Beringa (t = -6.7; p < .001; df = 28). In all, the Beringa villagers consumed less maize than many of their Wari-era counterparts in the Peruvian Andes (Figure 10).

### 5.7 | Protein resources at Beringa and other Wariaffiliated sites

MH populations in the nearby Nasca drainage to the north (mean  $\delta^{15}N_{bone\ collagen} = 8.8_{00}^{\circ}$  [Kellner and Schoeninger, 2008]) exhibit

18 WILEY ANTHROPOLOGY



**FIGURE 10** Stable isotope values from bone collagen from five MH samples in the Peruvian Andes (Finucane et al. 2006; Finucane, 2009; Kellner and Schoeninger, 2008; Slovak and Payton, 2011)

significantly lower  $\delta^{15}$ N values relative to Beringa (t = 5.75; df = 53; p < .0001); it is nearly 2‰ lower on average. This suggests that the Beringa peoples likely consumed greater amounts of higher trophic level foods (i.e., more protein) than MH Nasca communities. Those Beringa foods may have included marine resources and other carbon enriched foods that were high in protein, such as kiwicha. (Manuring of crops also could have resulted in elevated nitrogen isotope ratios among Beringa peoples [Szpak, 2014; Szpak, Millaire, White, & Long-staffe, 2012]; see discussion below.) When compared with the coastal Wari-era population at Ancón (mean  $\delta^{15}$ N<sub>bone collagen</sub> = 14.1‰) (Slovak and Paytan, 2011), the Beringa community, not surprisingly, consumed significantly less marine resources (t = -12.64; df = 51; p < .0001).

The stable nitrogen isotope ratios at Beringa are statistically similar to Conchopata (mean  $\delta^{15}N_{\text{bone collagen}} = 11.0\%$ ), and while much of this similarity is related to the consumption of terrestrial animals (C3derived protein) at both sites, Beringa families also consumed carbon enriched protein (possibly marine), as supported by several lines of evidence: nearly 800 marine mollusk shells, an average  $\delta^{15}N_{\text{bone collagen}}$ value of 10.6%, and the comparisons to the Kellner and Schoeninger (2007) and Froehl et al. (2012) models. At Conchopata, in contrast, there is no marine food refuse (Rosenfeld, 2011), and it is located 220 linear km from the Pacific coast. Furthermore, the average  $\delta^{15}N_{\text{bone collagen}}$ value of 11% at Conchopata has led Finucane et al. (2006) to suggest that manuring of crops likely contributed to the elevated  $\delta^{15} N$  values. That latter interpretation has been supported by experimental research in other parts of the Andes and elsewhere (Szpak, 2014; Szpak et al., 2012). Faunal analysis at each site also shows that Beringa had much less camelid and guinea pig remains (1,087 camelid bones and soft tissue pieces and 195 guinea pig bones) (Gladwell, 2002) than Conchopata (3,983 camelid bones and 3,687 rodent (mostly guinea pig) bones) (Rosenfeld, 2011), both in terms of absolute counts and percentage of entire faunal assemblage. Freshwater shrimp (C. caementarius) was another key resource at Beringa (Gladwell, 2004), which likely results in  $\delta^{15}$ N values slightly higher than the terrestrial herbivores (Miller et al., 2010; Schoeninger and DeNiro, 1984). *Cochayuyo (Porphyra columbina)*, a consumable seaweed also may have been a food source, but it would not have preserved, so its role in Beringa diets is unknown.

At the Wari heartland, commoner site of Marayniyoq (mean  $\delta^{15}N = 9.7\%$ ), the population consumed significantly less nitrogen enriched foods than those at Beringa (t = 3.46; df = 95; p = .0008), revealing the Marayniyoq dependence on terrestrial protein and Beringa's greater reliance on carbon enriched protein (Figure 10). (Finucane did not analyze bone carbonates at Conchopata and Marayniyoq, so those data cannot be compared with the Kellner and Schoeninger [2007] and Froehl et al. [2012] models.)

In light of the faunal and botanical remains and stable isotope data, the Beringa and heartland Wari communities had quite distinct menus and consumption patterns: Conchopata and Marayniyoq families had an abundance of maize and terrestrial protein, while Beringa families consumed more  $C_3$  plant sources with relatively less contributions from maize, and they consumed some carbon enriched protein, such as marine foods. This suggests that the Beringa inhabitants were not completely closed off from accessing the resources of the Pacific coast, whether through trade or sojourns to the Pacific. More broadly, this hints at local autonomy in terms of maintaining trade alliances with coastal peoples or preserving access routes to the coast even as Wari influence infiltrated the southern Andean region.

# 5.8 | Local agency, Wari imperial policies, and mediated outcomes

The findings presented here show that Beringa diets, as measured by stable carbon and nitrogen isotope analyses, did not significantly change with Wari imperial influence in the Majes Valley. This reveals the durability of several aspects of local diets and foodways at Beringa. It is unclear, however, whether this continuity in foodways at Beringa was by (a) imperial design; (b) local agency (e.g., resistance to Wari efforts to alter local diets); (c) weak imperial influence; or (d) a mediated outcome.

First, if Wari imperial policy intended to leave local foodways intact, focusing instead on other transformations in the Majes Valley and elsewhere, then the continuity in diet at Berigna would be expected. As an example, the later Inka empire (1450-1532 CE) required that some subject groups maintain local dress styles and language (Cobo, 1979 [1653]). Documenting this kind of continuity in local practices might be interpreted as local agency rather than an effect of imperial policies that insisted on the maintenance of certain local traditions. Thus, knowledge of these kinds of Inka policies reminds us of their concerted efforts to create subject communities either by imposing changes or by leaving some social and cultural practices intact. As such, we should be cautious about our expectations that local groups had unlimited agential capacities to resist imperial demands. Although the western narrative of individuals "pulling themselves up by the bootstraps", independently creating their own conditions, and resisting imperial influence is a strong theoretical force, scholars should consider other explanations when patterns of continuity are observed (i.e., it

PHYSICAL ANTHROPOLOGY WILEY | 19

may have been part of the imperial framework to maintain certain local practices).

Second, however, it remains unknown whether (and if so, to what extent) the Beringa community explicitly endeavored to maintain local food production and consumption patterns (i.e., local choice) as other practices of local lifeways were changing (e.g., there were new ceramic styles and textile production practices in the MH; Quequezana Lucano et al., 2012). Did they successfully resist Wari policies that would have impacted their local food production and consumption practices, resulting in stable diets through time? Was that resistance actualized through conflict? The high rate of trauma (33% of adults) at Beringa (Tung, 2007a) demonstrates that conflict occurred, but as Tung (2012) has subsequently argued, conflicts were not likely between Beringa inhabitants and Wari agents because the absence of Wari administrative structures in the Majes Valley suggests that Wari agents were not consistently present there. Instead, Wari regional influence and Wari direct rule in nearby regions (e.g., at Cerro Baúl in Moquegua valley; Williams, 2001) likely contributed to destabilizing regional political arrangements, resulting in ripples of conflict between groups in the Arequipa region (i.e., intra-regional conflict rather than local vs. Wari conflict) (Tung, 2012). Of course, Beringa villagers could have challenged Wari policies in other non-violent ways to overcome the imposition of non-local demands (e.g., Wari demands for tribute or blocked trade routes by Wari and/or Wari allies). Local actions that challenged foreign policies -whether violent or not-could have served to sustain local foodways at Beringa.

The third possibility recognizes that Wari imperial influence at Beringa may have been inconsequential, such that there was little significant effect on Beringa people's daily lives. The previously documented changes in local material culture from early MH to late MH at the nearby site of La Real may have resulted from local desires and efforts to obtain those exotic goods as markers of status (Jennings et al., 2015), rather than a hegemonic imposition of new styles. Thus, the absence of detectable changes in diet may be a reflection of the limits of Wari's imperial reach.

The fourth scenario highlights the possibility that dietary continuity was the result of mediated policies and practices by Beringa and Wari agents (and unknown groups of allies and foes). That is, the observed continuity in diet could have been shaped by ongoing negotiations and mundane, local practices that constrained the ability of Wari agents and Wari allies to transform Beringa diets in any substantial way. As a point of comparison, Spanish colonialism in Peru led to a massive reorganization and forced resettlement of indigenous peoples, but those colonial policies had to operate within existing indigenous systems, leading to negotiated settlements and outcomes that were not wholly of the Spanish Crown's making (Wernke, 2013). Furthermore, even as indigenous peoples experienced dramatic changes to the architecture of their homes, communal spaces, and locations of settlements during the early years of Spanish colonialism, native peoples at the site of Malata in the Colca Valley (located up-river from Beringa) were not introduced to foreign (Eurasian) animals as a foodsource or other resource (e.g., no sheep for wool) in the early decades of the Spanish colonial era (deFrance, Wernke, & Sharpe, 2017). Instead, local camelid

husbandry practices were maintained, and the Spaniards extracted the camelid wool textiles as a source of tribute (deFrance et al. 2017). Wari imperial rule—both direct and indirect—also would have had to negotiate the varying local socio-political and ecological conditions and learn to adapt to the availability of local resources and traditions. Indeed, archaeological studies of imperialism and colonial encounters often report mediated outcomes in a variety of domestic, religious, and political situations (Revell, 2009; Robinson, 2013; Russell, 2005; Voss, 2008; Wernke, 2007); they result from intentional and overt negotiations, as well as mundane practices shaped by habitus (Bourdieu, 1977).

Although this study focused on diet, previous research has examined how other aspects of community life changed in the middle Majes Valley during the time of Wari influence, documenting, for example, significant changes in ceramic and textile styles and production techniques. The local Ramada ceramic style disappears in the late MH at the neighboring site of La Real (where Wari style Robles Moqo and Viñaque ceramics begin to appear) (Jennings et al., 2015), and the transition from early to late MH is marked by significant increases in painted ceramic spindle whorls (Goldstein and Yepez Alvarez, 2012), plain weave, warp-faced textiles (Quequezana Lucano et al., 2012), and dovetailed and interlocked tapestries (Quequezana Lucano et al., 2012). That latter style is associated with the noble or elite class within the Wari state (Bergh, 2012). The significantly greater presence of Wari-style ceramics, textile production tools, and textiles at La Real likely signals stronger ties to Wari, at least among Majes Valley elites. Those material culture data suggest that Wari imperial influence in the Majes Valley was altering the way people produced material culture and adorned their bodies with cloth. The paleodiet data from Beringa, in contrast, suggest that greater interaction with Wari-derived material culture did not extend to include significant changes in the foods people consumed.

This was not the case at Tiwanaku-affiliated sites (ca. 600-900 CE) in northern Chile (San Pedro de Atacama and Azapa) and the Moguegua Valley of southern Peru, where Goldstein's (2003) study of pre-Tiwanaku and Tiwanaku era sites documented a dramatic change in culinary traditions, both in foods and beverages consumed (and see Sandness, 1992; Somerville et al., 2015) and in the ways of serving them. Of particular note is the increase in maize consumption in the Moguegua Valley from pre-Tiwanaku to Tiwanaku times (Sandness, 1992) and the general abundance of maize in Tiwanaku-era diets (Somerville et al., 2015). The significant increase in keros-Tiwanaku drinking cups-demonstrates that the maize was often consumed as chicha (maize beer), particularly during feasts that created social and political bonds between the many communities from the Tiwanaku highlands to the Pacific coast, especially along the Moguegua corridor (Goldstein, 2003). The temporal difference in culinary practices observed at Tiwanaku-affiliated sites-and the absence of them at Beringa-may be partly explained by geographic factors and historical precedence; Beringa is hundreds of kilometers over a mountainous landscape from the Wari heartland, compared with Moguegua Valley's proximity to the Tiwanaku core, as well as longer-standing ties between valley and highland groups in that region (Blom, 2005).

<sup>20</sup> WILEY



### 6 | CONCLUSIONS

Amidst the immense socio-political changes of the MH, diet remained constant at Beringa. That continuity in food consumption patterns has implications for understanding food production and food procurement strategies too, suggesting for example, that the procurement of camelid and marine resources were not hindered by the development of new Wari alliances and trade networks. Beringa peoples maintained a fundamental aspect of their local lifeways: access to terrestrial, riverine, and some marine protein. But their access to the socially valued food-maize-did not increase, despite their location in an excellent maize-growing zone. The social and political importance of maize, especially maize beer, has been documented elsewhere in the Andes (D'altroy, 2002; Goldstein, 2003; Morris, 1979), and at Beringa, its social importance is hinted at in the carefully bundled maize cobs that were placed with burials. However, the lower quantities of maize relative to other contemporaneous sites (and by implication, less quantities of chicha) may not have been solely a result of exclusion by other groups. Excavations at Beringa revealed large quantities of S. molle seeds, suggesting that chicha de molle was a favored fermented beverage (Tung, 2007b). Perhaps Beringa people had little interest or taste for chicha de maize, or they may have increased production of chicha de molle when they could not gain ready access to chicha de maize.

Research in other Andean regions can further illuminate whether dietary continuity during this time of socio-political change included only Beringa and the Nasca region (Kellner and Schoeninger, 2008), or whether it was part of a larger pattern of durable, local foodways in Wariinfluenced regions. Future and ongoing paleodiet studies at the Majes Valley sites of Uraca (Scaffidi et al., 2017) and La Real will help to clarify these points, as will studies in other Wari regions (Knudson, Giersz, Więckowski, & Tomczyk, 2017). If dietary consistency is documented throughout many Wari areas, then this may suggest that imperial policies and practices did little to alter local foodways. Alternatively, there could have been intense, local resistance to changes in daily and ritual consumption of foods, showing the limits of imperial infiltration into new cultural and ecological zones. It is also possible that certain foods were locally produced, but not consumed by local peoples, hinting at either imperial tribute demands or trade obligations. For example, Beringa peoples may have increased agricultural production (of maize perhaps) during Wari times, as was observed in the Moquegua Valley (Williams, 2002), but it may have been shipped out, such that they never enjoyed the fruits of their labor.

As more studies of Wari imperialism (and other pre-hispanic empires) are undertaken, results may show that some Wari regions exhibit significant changes in diet, while others do not. The patterning of those dietary changes may be quite revealing about Wari state decisions regarding food production and extraction priorities. To evaluate those, additional lines of evidence (e.g., faunal, botanical, data on storage vessels and facilities, agricultural production potentials, etc.) must be sought to examine how practices related to foodways and diet were shaped by top-down imperial policies or imperial indifference, local efforts to rebuff change, intentional negotiations, and/or unintentional outcomes of those novel interactions.

At the local level, this paleodiet study showed that there was a change in diet through the lifecourse: maize consumption (or some

other carbon enriched food) significantly increased from childhood to adulthood for those at Beringa. That was the only patterned, dietary distinction observed.

Other intrasite comparisons revealed homogeneity. Boys and girls had similar childhood diets on average, and men and women had similar adulthood diets. Moreover, there were no differences in diet between distinct tomb groups (though there were some idiosyncratic distinctions). Those similarities hint at equal access to foods by different subgroups, perhaps reflecting more egalitarian principles at the community-site level. Although comparisons to other sites in the valley show marked distinctions in access to exotic textiles and other material culture—artifactual evidence for class hierarchies and gender distinctions within the Majes Valley as a whole—the Beringa community may have been characterized by practices of inclusion, inasmuch as it related to foodways and access to dietary resources.

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### REFERENCES

Ambrose, S. (1990). Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science*, 17, 430–451.

American Journal of PHYSICAL ANTHROPOLOGY WILEY<sup>2</sup>

- Ambrose, S. H. (1991). Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. *Journal of Archaeological Science*, 18, 293–317.
- Ambrose, S. H. (1993). Isotopic analysis of paleodiets: Methodological and interpretive considerations. In M. K. Sandford (Ed.), *Investigations* of ancient human tissue: Chemical analyses in anthropology (pp. 59– 130). USA: Gordon and Breach Science Publishers.
- Ambrose, S. H. (2002). Controlled diet and climate experiments on nitrogen isotope ratios of rats. *Biogeochemical approaches to paleodietary analysis*: Springer. p 243–259.
- Ambrose, S. H., Butler, B. M., Hanson, D., Hunter-Anderson, R., & Krueger, H. (1997). Stable isotopic analysis of human diet in the Marianas Archipelago, Western Pacific. *American Journal of Physical Anthropology*, 104, 343–361.
- Ambrose, S. H., & Deniro, M. J. (1987). Bone nitrogen isotope composition and climate. *Nature*, 325, 201.
- Ambrose, S. H., & Norr, L. (1993). Experimental evidence for the relationship of carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In J Lambert & G. Grupe (Eds.) *Prehistoric human bone: Archaeology at the molecular level* (pp.1–38). Berlin: Springer-Verlag.
- Beasley, M. M., Bartelink, E. J., Taylor, L., & Miller, R. M. (2014). Comparison of transmission FTIR, ATR, and DRIFT spectra: Implications for assessment of bone bioapatite diagenesis. *Journal of Archaeological Science*, 46, 16–22.
- Bedregal, P. S., Mendoza, P. A., Ubillús, M. S., Yépez, W., Jennings, J., & Montoya, E. H. (2015). Wari influence in southern Peru: Provenance study of middle horizon pottery from the archaeological site of La Real using k O-INAA. *Journal of Radioanalytical and Nuclear Chemistry*, 306, 729–736.
- Bergh, S. E. (2012). Tapestry-woven tunics. In S. E. Bergh (Ed.) Wari: Lords of the ancient Andes (pp. 159–191). Cleveland: Thames & Hudson; Cleveland Museum of Art.
- Blom, D. E. (2005). Embodying borders: Human body modification and diversity in Tiwanaku society. *Journal of Anthropological Archaeology*, 24, 1–24.
- Bocherens, H., & Drucker, D. (2003). Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: Case studies from recent and ancient terrestrial ecosystems. *International Journal of Osteoarchaeology*, 13, 46–53.
- Bourdieu, P. (1977). *Outline of a theory of practice*. Cambridge: Cambridge University Press.
- Bray, T. L. (2003). The commensal politics of early states and empires. The archaeology and politics of food and feasting in early states and empires (pp. 1–13). New York: Springer.
- Calvin, M., & Benson, A. A. (1948). The path of carbon in photosynthesis. *Science*, 107, 476–480.
- Chisholm, B. S., Nelson, D. E., & Schwarcz, H. P. (1982). Stable-carbon isotope ratios as a measure of marine versus terrestrial protein in ancient diets. *Science*, *216*, 1131–1132.
- Cobo, B. (1979). [1653]. History of the Inca empire: An account of the Indians' customs and their origin, together with a treatise on Inca legends, history, and social institutions. Austin: University of Texas Press.
- Cook, A. G., & Glowacki, M. (2003). Pots, politics, and power: Wari ceramic assemblages and imperial administration. In: Bray T, editor. The archaeology and politics of food and feasting in early states and empires. New York: Kluwer Academic/Plenum Publishers. p 173-202.
- Coplen, T. B. (1994). Reporting of stable hydrogen, carbon, and oxygen isotopic abundances. *Pure and Applied Chemistry*, *66*, 273–276.

- Craig, H. (1961). Standard for reporting concentrations of deuterium and oxygen-18 in natural waters. *Science*, 133, 1833–1834.
- D'Altroy, T. N. (2002). *The Incas* (Vol. xv, p. 391). Malden, MA: Blackwell Publishers.
- deFrance, S. D., Wernke, S. A., & Sharpe, A. E. (2017). Conversion and persistence: Analysis of faunal remains from an early Spanish Colonial Doctrinal settlement in highland Peru. *Latin American Antiquity*, *27*, 300–317.
- DeNiro, M. J. (1985). Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature*, 317, 806–809.
- DeNiro, M. J., & Epstein, S. (1978). Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta*, 42, 495–506.
- DeNiro, M. J., & Epstein, S. (1981). Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta*, 45, 341–351.
- Dietler, M. (2006). Culinary encounters: Food, identity, and colonialism. In K. C. Twiss (Ed.) *The archaeology of food and identity* (pp. 218– 242). Carbondale: Center for Archaeological Investigations.
- Finucane, B. (2009). Maize and sociopolitical complexity in the Ayacucho Valley, Peru. *Current Anthropology*, *50*, 535–545.
- Finucane, B., Maita, P., & Isbell, W. H. (2006). Human and animal diet at Conchopata, Peru: Stable isotope evidence for maize agriculture and animal management practices during the Middle Horizon. *Journal of Archaeological Science*, 33, 1766–1776.
- Freidel, D., & Reilly, III F. K. (2010). The flesh of god: Cosmology, food, and the origins of political power in ancient southeastern Mesoamerica (pp. 635–680). Pre-Columbian Foodways: Springer.
- Froehle, A. W., Kellner, C. M., & Schoeninger, M. J. (2012). Multivariate carbon and nitrogen stable isotope model for the reconstruction of prehistoric human diet. *American Journal of Physical Anthropology*, 147, 352–369.
- Garcia Márquez, M., & Bustamante Montoro, R. (1990). Arqueología del valle de Majes. *Gaceta Arqueológica Andina 18/19*, 25-40.
- Garvie-Lok, S. J., Varney, T. L., & Katzenberg, M. A. (2004). Preparation of bone carbonate for stable isotope analysis: The effects of treatment time and acid concentration. *Journal of Archaeological Science*, 31, 763–776.
- Gladwell, R. (2004). Animals among the dead: A Middle Horizon and Late Intermediate Period archaeological site in southwestern Peru (Senior honor's thesis). University of New, Mexico, Albuquerque.
- Gladwell, R. R. (2002). Beringa faunal report for the Beringa Bioarchaeology and Archaeology Project. Unpublished report.
- Goldstein, P. S. (2003). From Stew-Eaters to Maize-Drinkers: The Chicha Economy and the Tiwanuku Expansion. In: Bray TL, editor. *The archaeology and politics of food and feasting in early states and empires* (pp. 143–172). New York: Kluwer Academic/Plenum Publishers.
- Gladwell, R., Pacheco, L., Atudorei, V., & Tung, T. A. (2004). Atomic llama: Can stable isotope analysis of camelid hair be used to measure prehistoric Andean pastorlaist migration and herding practices? *The* 69th Annual Meeting of the Society for American Archaeology. Montreal, Canada.
- Goldstein, R. C., & Yepez Alvarez, W. (2012). Instrumentos textiles: Ruecas. In Yepez Alvarez W, and Jennings J, editors. Wari en Arequipa? Arequipa: Museo arqueologico jose maria morante (pp. 128–144). Arequipa: Universidad Nacional de San Agustin.
- Haaland, R. (2007). Porridge and pot, bread and oven: Food ways and symbolism in Africa and the Near East from the Neolithic to the present. *Cambridge Archaeological Journal*, 17, 165–182.

# 22 WILEY MILEY American Journal of PHYSICAL ANTHROPOLOGY

- Haaland, R. (2012). Changing food ways as indicators of emerging complexity in Sudanese Nubia: From Neolithic agropastoralists to the Meroitic civilisation. *Azania: Archaeological Research in Africa*, 47, 327–342.
- Harrison, R. G., & Katzenberg, M. A. (2003). Paleodiet studies using stable carbon isotopes from bone apatite and collagen: Examples from Southern Ontario and San Nicolas Island, California. *Journal of Anthropological Archaeology*, 22, 227–244.
- Hastorf, C. (1990). The effect of the Inka state on Sausa agricultural production and crop consumption. *American Antiquity*, *55*, 262–290.
- Hastorf, C. A. (1991). Gender, space, and food in prehistory. In Engendering archaeology: women and prehistory, eds., Joan M. Gero and Margaret W. Conkey. pp. 132–159. Oxford: Blackwell Publishing.
- Hastorf, C. A. (2002). Agricultural production and consumption. In T. D'Altroy & C. A. Hastorf (Eds.), *Empire and domestic economy* (pp. 155–178). New York: Kluwer Academic/Plenum Publishers.
- Hastorf, C. A., & D'altroy, T. N. (2002). The domestic economy, households, and imperial transformation. In *Empire and Domestic Economy*, edited by T. N. D'Altroy and C. A. Hastorf, pp. 3–25. New York: Kluwer Academic/Plenum Publishers.
- Hatch, M., Slack, C., & Johnson, H. S. (1967). Further studies on a new pathway of photosynthetic carbon dioxide fixation in sugar-cane and its occurrence in other plant species. *Biochemical Journal*, 102, 417.
- Hatch, M. D., & Slack, C. R. (1966). Photosynthesis by sugar-cane leaves: A new carboxylation reaction and the pathway of sugar formation. *Biochemical Journal*, 101, 103.
- Hedges, R. E. M., & Reynard, L. M. (2007). Nitrogen isotopes and the trophic level of humans in archaeology. *Journal of Archaeological Sci*ence, 34, 1240–1251.
- Hospodar, M. (2004). Aphrodisiac foods: Bringing heaven to earth. Gastronomica, 4, 82-93.
- Hyder, A. A., Maman, S., Nyoni, J. E., Khasiani, S. A., Teoh, N., Premji, Z., & Sohani, S. (2005). The pervasive triad of food security, gender inequity and women's health: Exploratory research from sub-Saharan Africa. African Health Sciences, 5, 328–334.
- Jennings, J., Tung, T. A., Yépez Álvarez, W. J., Lucano, G. C. Q., & Hurtado, M. A. L. (2015). Shifting local, regional, and interregional relations in middle Horizon Peru: Evidence from La Real. *Latin American Antiquity*, 26, 382–400.
- Jim, S., Ambrose, S. H., & Evershed, R. P. (2004). Stable carbon isotopic evidence for differences in the dietary origin of bone cholesterol, collagen and apatite: Implications for their use in palaeodietary reconstruction. *Geochimica et Cosmochimica Acta*, 68, 61–72.
- Johnson, H. S., & Hatch, M. (1968). Distribution of the C4-dicarboxylic acid pathway of photosynthesis and its occurrence in dicotyledonous plants. *Phytochemistry*, *7*, 375–380.
- Kellner, C. M., & Schoeninger, M., J. (2008). Wari's imperial influence on local Nasca diet: The stable isotope evidence. *Journal of Anthropological Archaeology*, 27, 226–243.
- Kellner, C. M., & Schoeninger, M. J. (2007). A simple carbon isotope model for reconstructing prehistoric human diet. *American Journal of Physical Anthropology*, 133, 1112–1127.
- King, C. L., Tayles, N., & Gordon, K. C. (2011). Re-examining the chemical evaluation of diagenesis in human bone apatite. *Journal of Archaeological Science*, 38, 2222–2230.
- King, H., Delgado Pérez, M. M., & Metropolitan Museum of Art (New York N.Y.). (2012). Peruvian featherworks: Art of the Precolumbian era (vol. ix, p. 222). New York, New Haven: Metropolitan Museum of Art; Distributed by Yale University Press.
- Knudson, K. J., Giersz, M., Wieckowski, W., & Tomczyk, W. (2017). Reconstructing the lives of Wari elites: Paleomobility and paleodiet

at the archaeological site of Castillo de Huarmey, Peru. Journal of Archaeological Science: Reports, 13, 249-264.

- Knudson, K. J., Torres-Rouff, C., & Stojanowski, C. M. (2015). Investigating human responses to political and environmental change through paleodiet and paleomobility. *American Journal of Physical Anthropol*ogy, 157, 179–201.
- Knudson, K. J., & Tung, T. A. (2011). Investigating regional mobility in the southern hinterland of the Wari empire: Biogeochemistry at the site of Beringa, Peru. American Journal of Physical Anthropology, 145, 299–310.
- Koch, P. L., Tuross, N., & Fogel, M. (1997a). The effects of sample treatment and diagenesis on the isotopic integrity of carbonate in biogenic hyydroxylapatite. *Journal of Archaeological Science*, 24, 417– 429.
- Koch, P. L., Tuross, N., & Fogel, M. L. (1997b). The Effects of Sample Treatment and Diagenesis on the Isotopic Integrity of Carbonate in Biogenic Hydroxylapatite. *Journal of Archaeological Science*, 24, 417–429.
- Koontz, C. B. (2011). Pre-Wari and Wari health, trauma, and tradition in the Majes and Siguas Valleys, Department of Arequipa, Peru. Center for Latin American Studies Graduate Student Conference. Vanderbilt University.
- Kortschak, H. P., Hartt, C. E., & Burr, G. O. (1965). Carbon dioxide fixation in sugarcane leaves. *Plant Physiology*, 40, 209.
- LeCount, L. J. (2001). Like water for chocolate: Feasting and political ritual among the Late Classic Maya at Xunantunich, Belize. American Anthropologist, 103, 935–953.
- Lee-Thorp, J., & Sponheimer, M. (2003). Three case studies used to reassess the reliability of fossil bone and enamel isotope signals for paleodietary studies. *Journal of Anthropological Archaeology*, 22, 208–216.
- Lee-Thorp, J. A., Sealy, J. C., & Van der Merwe, N. J. (1989). Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. *Journal of Archaeological Science*, 16, 585–599.
- Lee-Thorp, J. A., & van der Merwe, N. J. (1991). Aspects of the chemistry of modern and fossil biological apatites. *Journal of Archaeological Science*, 18, 343–354.
- Malpass, M. A. (2001). Sonay: Un centro Wari celular ortogonal en el Valle de Camana, Perú. Boletín de Arqueología PUCP, Lima 5, 51–68.
- Marsteller, S. J., Zolotova, N., & Knudson, K. J. (2017). Investigating economic specialization on the central Peruvian coast: A reconstruction of Late Intermediate Period Ychsma diet using stable isotopes. American Journal of Physical Anthropology, 162, 300–317.
- Miller, M. J., Capriles, J. M., & Hastorf, C. A. (2010). The fish of Lake Titicaca: Implications for archaeology and changing ecology through stable isotope analysis. *Journal of Archaeological Science*, 37, 317–327.
- Minagawa, M., & Wada, E. (1984). Stepwise enrichment of 15 N along food chains: Further evidence and the relation between  $\delta$  15 N and animal age. *Geochimica et Cosmochimica Acta*, 48, 1135–1140.
- Morris, C. (1979). Maize beer in the economics, politics, and religion of the Inca empire. Fermented food beverages in nutrition (pp. 21–35). New York: Academic Press.
- Nash, D. (2011). Fiestas y la economía política Wari en Moquegua, Perú. *Chungará (Arica)*, 43, 221-242.
- Nash, D. (2016). Vernacular versus state housing in the Wari Empire. In C. T. Halperin & L. E. Schwartz (Eds.), *Vernacular architecture in the Pre-Columbian Americas* (pp. 91–112). London: Routledge.
- Nash, D., & Williams, P. R. (2004). Architecture and power on the Wari-Tiwanaku frontier. In K. Vaughn, C. Conlee, & D. Ogburn (Eds.), *The foundations of power in the prehispanic Andes* (pp. 151–174). Arlington: American Anthropological Association.

ANTHROPOLOGY WILEY<sup>23</sup>

- Nielsen-Marsh, C. M., & Hedges, R. E. M. (2000). Patterns of Diagenesis in Bone II: Effects of Acetic Acid Treatment and the Removal of Diagenetic CO32–. *Journal of Archaeological Science*, 27, 1151–1159.
- O'Connell, T. C., Kneale, C. J., Tasevska, N., & Kuhnle, G. G. C. (2012). The diet-body offset in human nitrogen isotopic values: A controlled dietary study. American Journal of Physical Anthropology, 149, 426–434.
- Owen, B. (2007). The Wari heartland on the Arequipa Coast: Huamanga ceramics from Beringa, Majes. *Andean Past*, *8*, 287–373.
- Owen, B. (2010). Wari in the Majes-Camana Valley: A different kind of horizon. In J. Jennings (Ed.), *Beyond wari walls* (pp. 57–78). Albuquerque: University of New Mexico.
- Pestle, W. J., Crowley, B. E., & Weirauch, M. T. (2014). Quantifying inter-laboratory variability in stable isotope analysis of ancient skeletal remains. *PloS One*, 9, e102844.
- Pestle, W. J., Torres-Rouff, C., & Hubbe, M. (2016). Modeling diet in times of change: The case of Quitor, San Pedro de Atacama, Chile. *Journal of Archaeological Science: Reports*, 7, 82–93.
- Pucéat, E., Reynard, B., & Lécuyer, C. (2004). Can crystallinity be used to determine the degree of chemical alteration of biogenic apatites?. *Chemical Geology*, 205, 83–97.
- Purcell, N. (2003). The way we used to eat: Diet, community, and history at Rome. American Journal of Philology, 124, 329–358.
- Quequezana Lucano, G. C., Yepez ALvarez, I., & Lopez Hurtado, M. A. (2012). Tecnicas textiles: Vestidos e identidad colectiva. In W. Yepez Alvarez & J. Jennings (Ed.), *Wari en Arequipa*? (pp. 98–127). Arequipa: Universidad Nacional de San Agustin.
- Ranson, S. L., & Thomas, M. (1960). Crassulacean acid metabolism. Annual Review of Plant Physiology, 11, 81–110.
- Revell, L. (2009). Roman imperialism and local identities. Cambridge: Cambridge University Press.
- Robinson, D. (2013). Polyvalent metaphors in south-central California missionary processes. *American Antiquity*, 78, 302–321.
- Rosenfeld, S. (2011). Foodways and sociopolitics in the Wari empire of Peru, A.D. 600 - 900 (PhD). Stanford University, Palo Alto. p. 251.
- Russell, L. (2005). "Either, or, Neither Nor": Resisting the Production of Gender, Race and Class Dichotomies in the Pre-Colonial Period. In, The Archaeology of Plural and Changing Identities, eds., Eleanor C. Casella and Chris Fowler. pp. 33–51. Boston, MA: Springer.
- Samec, C., Morales, M., & Yacobaccio, H. (2014). Exploring human subsistence strategies and environmental change through stable isotopes in the dry Puna of Argentina. *International Journal of Osteoarchaeol*ogy, 24, 134–148.
- Sandness, K. (1992). Temporal and spatial dietary variability in the Osmore Drainage, Southern Peru: The isotope evidence (MA thesis). University of Nebraska at Lincoln, Lincoln.
- Santana-Sagredo, F., Hubbe, M., & Uribe, M. (2015). Isotopic evidence for marine consumption and mobility in the Atacama Desert (Quillagua, Northern Chile). *International Journal of Osteoarchaeology*,
- Scaffidi, B. K., Vang, N., & Tung, T. A. (2017). Diet in coastal Arquipa, Peru, at the dawn of the Wari empire. 82 Annual Meeting of the Society for American Archaeology. Vancouver, Canada.
- Schoeninger, M. J., & DeNiro, M. J. (1984). Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta*, 48, 625–639.
- Schoeninger, M. J., DeNiro, M. J., & Tauber, H. (1983). Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science*, 220, 1381–1383.

- Slovak, N. M., & Paytan, A. (2011). Fisherfolk and farmers: Carbon and nitrogen isotope evidence from Middle Horizon Ancón, Peru. International Journal of Osteoarchaeology, 21, 253–267.
- Smith, B. N., & Epstein, S. (1971). Two categories of 13C/12C ratios for higher plants. Plant Physiology, 47, 380–384.
- Somerville, A. D., Goldstein, P. S., Baitzel, S. I., Bruwelheide, K. L., Dahlstedt, A. C., Yzurdiaga, L., ... Schoeninger, M. J. (2015). Diet and gender in the Tiwanaku colonies: Stable isotope analysis of human bone collagen and apatite from Moquegua, Peru. American Journal of Physical Anthropology, 158, 408–422.
- Sørensen, M. L. S. (2000). Gender archaeology (vol. xi, pp. 236). Cambridge, UK, Malden, MA: Polity Press; Blackwell.
- Szpak, P. (2014). Complexities of nitrogen isotope biogeochemistry in plant-soil systems: Implications for the study of ancient agricultural and animal management practices. *Frontiers in Plant Science*, 5, 288.
- Szpak, P., Longstaffe, F. J., Millaire, J.-F., & White, C. D. (2014). Large variation in nitrogen isotopic composition of a fertilized legume. *Journal of Archaeological Science*, 45, 72–79.
- Szpak, P., Millaire, J.-F., White, C. D., & Longstaffe, F. J. (2012). Influence of seabird guano and camelid dung fertilization on the nitrogen isotopic composition of field-grown maize (Zea mays). *Journal of Archaeological Science*, 39, 3721–3740.
- Tieszen, L. L., Iversen, E., & Matzner, S. (1992). Dietary reconstruction based on carbon, nitrogen, and sulfur stable isotopes in the Atacama desert, northern Chile. *Proceedings of the First World Congress on Mummy Studies*. Tenerife, Spain, pp. 427–441.
- Ting, I. (1985). Crassulacean acid metabolism. Annual Review of Plant Physiology, 36, 595-622.
- Tripcevich, N. (2009). Report on the XRF Analysis of Obsidian from Beringa. Berkeley Archaeological Research Facility. pp. 1–3.
- Trueman, C. N., Privat, K., & Field, J. (2008). Why do crystallinity values fail to predict the extent of diagenetic alteration of bone mineral?. *Palaeogeography, Palaeoclimatology, Palaeoecology, 266*, 160–167.
- Tung, T. A. (2003). A bioarchaeological perspective on wari imperialism in the Andes of Peru: A view from heartland and hinterland skeletal populations [dissertation]. Chapel Hill: University of North Carolina.
- Tung, T. A. (2007a). Trauma and violence in the Wari empire of the Peruvian Andes: Warfare, raids, and ritual fights. *American Journal of Physical Anthropology*, 133, 941–956.
- Tung, T. A. (2007b). The village of Beringa at the periphery of the Wari Empire: A site overview and new radiocarbon dates. *Andean past*, *8*, 253–286.
- Tung, T. A. (2012). Violence, ritual, and the Wari empire: A social bioarchaeology of imperialism in the ancient Andes. Gainesville: University Press of Florida.
- Tung, T. A. (n.d.). The Chronology of the Beringa Burials: Report for the Majes Valley Bioarchaeology Project. Vanderbilt University. pp. 1–7.
- Tung, T. A., Miller, M.,D., Santis, L., Sharp, E. A., & Kelly, J. (2016). Patterns of violence and diet among children during a time of imperial decline and climate change in the ancient Peruvian Andes. In A. VanDerwarker & G. Wilson (Eds.). *Food and Warfare* (pp. 193–228). Switzerland: Springer.
- Turner, B. (2015). Interpreting oral pathology at machu picchu, Peru. International Journal of Osteoarchaeology, 25, 502–514.
- Turner, B. L., Kamenov, G. D., Kingston, J. D., & Armelagos, G. J. (2009). Insights into immigration and social class at Machu Picchu, Peru based on oxygen, strontium, and lead isotopic analysis. *Journal of Archaeological Science*, 36, 317–332.
- Tykot, R. H. (2004). Stable isotopes and diet: You are what you eat. *Proceedings-International School of Physics Enrico Fermi*. IOS Press, Ohmsha, 1999. pp. 433-444.

### 24 WILEY PHYSICAL ANTHROPOLOGY

- Voss, B. L. (2008). Gender, race, and labor in the archaeology of the Spanish Colonial Americas. *Current Anthropology*, 49, 861–893.
- Wada, E. (1980). Nitrogen isotope fractionation and its significance in biogeochemical processes occurring in marine environments. In E. D. Goldberg, Y. Horibe, & K. Saruhashi (Eds.). *Isotope marine chemistry*. Tokyo: Uchida Rokahuko.
- Walker, P. L., & DeNiro, M. J. (1986). Stable nitrogen and carbon isotope ratios in bone collagen as indices of prehistoric dietary dependence on marine and terrestrial resources in southern California. American Journal of Physical Anthropology, 71, 51–61.
- Webb, E. C., White, C. D., Van Uum, S., & Longstaffe, F. J. (2015). Integrating cortisol and isotopic analyses of archeological hair: Reconstructing individual experiences of health and stress. *American Journal* of Physical Anthropology, 156, 577–594.
- Wernke, S. A. (2007). Negotiating community and landscape in the Peruvian Andes: A transconquest view. American Anthropologist, 109, 130–152.
- Wernke, S. A. (2013). Negotiated settlements: Andean communities and landscapes under Inka and Spanish colonialism. Gainesville: University Press of Florida.

- Williams, P. R. (2001). Cerro Baúl: A Wari center on the Tiwanaku frontier. *Latin American Antiquity*, 12(1):67–83.
- Williams, P. R. (2002). Rethinking disaster-induced collapse in the the demise of the Andean highland states: Wari and Tiwanaku. World Archaeology, 33, 361–374.
- Yoder, C., & Bartelink, E. J. (2010). Effects of different sample preparation methods on stable carbon and oxygen isotope values of bone apatite: A comparison of two treatment protocols. *Archaeometry*, *52*, 115–130.

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