



# A multi-isotope approach to reconstructing human residential mobility and diet during the Late Intermediate Period (1000–1450 CE) in highland Ancash, Peru

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## ABSTRACT

The Late Intermediate Period (LIP, c. 1000–1450 CE) was a time of cultural change in the Peruvian highlands. During this time, interpersonal violence increased, and settlements were placed in defensive locations at high elevations. High altitude settlement was also a proxy for agropastoral economies. Coinciding with these cultural and economic transformations were shifts in mortuary practices in which the deceased were buried in above-ground tombs, known as *chullpas*, and in caves. In this paper, we examine the implications of these changes with respect to diet and mobility through a multi-isotopic analysis of human burials from three LIP sites in the Conchucos region. We analyzed strontium ( $^{87}\text{Sr}/^{86}\text{Sr}$ ), and carbon and nitrogen ( $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ) isotopes in human skeletal remains ( $n = 101$ ) from burials at the sites of Marcacirca ( $n = 66$ ), Jato Viejo ( $n = 9$ ), and Ushcugaga ( $n = 26$ ). At all three sites, dietary mixing models using  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values suggest a diet based largely on maize and camelids, with minor consumption of  $\text{C}_3$  plants and guinea pig. Human enamel  $^{87}\text{Sr}/^{86}\text{Sr}$  values ranged from 0.7095 to 0.7125 and varied significantly between sites. All human  $^{87}\text{Sr}/^{86}\text{Sr}$  values resembled those found in the regional geology, suggesting that individuals buried at the three sites were probably from the Conchucos region. In addition, patterns in  $^{87}\text{Sr}/^{86}\text{Sr}$  values may indicate that the individuals buried in *chullpas*, and caves were members of extended kin groups. We conclude that groups living in Conchucos during the LIP created and maintained local exchange networks that exploited vertically stacked production zones.

## 1. Introduction

The Late Intermediate Period (LIP [c. 1000–1450 CE]) was a time when much of the Peruvian highlands entered a period of political fragmentation following the collapse of the Wari polity of the preceding Middle Horizon (c. 700–1000 CE) (Covey, 2008; Parsons and Hastings, 1988). These cultural transformations occurred in the period prior to the expansion of the Inca Empire (c. 1450–1532 CE) and are recognized by higher frequencies of skeletal evidence for interpersonal violence, and the relocation of large settlements to defensive locations at higher elevations (~above 3500 masl) (Álvarez Larrain and Greco, 2018; Arkush, 2008, 2011; Arkush and Stanish, 2005; Arkush and Tung, 2013; Bauer and Kellett, 2010; Bauer et al., 2010; Ibarra, 2021; Jolly and Kurin, 2017; Kellett, 2010; Lofaro et al., 2018; Kurin, 2013; Meddens and

Branch, 2010; Torres-Rouff et al., 2005; Tung, 2008; Tung et al., 2016).

Economic factors also account for the LIP movement of settlements into the high-altitude *puna* grassland (3600–4500 masl) (Bauer and Kellett 2010; Lane, 2006; Parsons et al., 1997), a landscape dominated by  $\text{C}_3$  grasses and conducive to agropastoral practices, including herding of domesticated camelids (llamas [*Lama glama*] and alpaca [*Vicugna pacos*]) and cultivation of grains and tubers. At the same time, these high elevation sites were positioned at altitudes exceeding the limits of other important crops of the LIP. Access to resources grown in lower elevations, such as maize (*Zea mays*), necessitated the movement of people or the establishment of exchange relationships with the inhabitants of different ecological production zones to acquire key resources not directly available to them (Murra, 1972, 1985).

Coinciding with the social and economic transformations of the LIP

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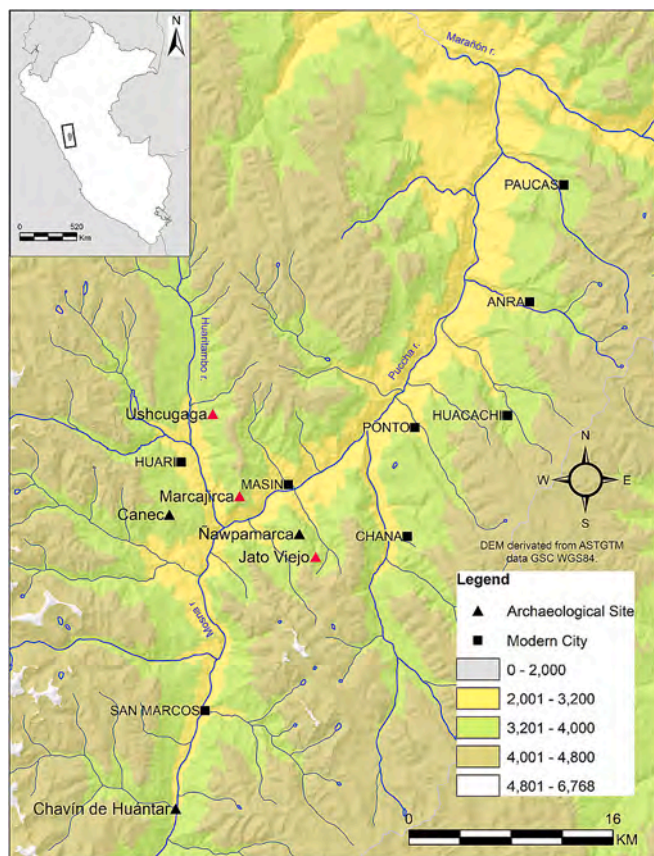
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were changes in mortuary practices, including the widespread use of above ground masonry chamber tombs known as *chullpas*, as well as interments within caves (Ibarra, 2021). Both kinds of burials frequently contained numerous individuals that were interred over multiple generations (Burger et al., 2021; Isbell, 1997; Lane et al., 2018). It is generally thought that *chullpas* and caves contained individuals related through kinship, and therefore have been identified as a material correlate for ancestor worship as a structuring organizing principal (Dillehay, 1995; Hyslop, 1977; Ibarra, 2021; Isbell, 1997; Mantha, 2009; Nielsen, 2008; Ringbauer et al., 2020; Velasco, 2014).

These changes raise questions about the types of strategies that highland peoples adopted to mediate the pressures of political fragmentation, how these strategies may have affected the types of dietary resources utilized, and the extent of regional mobility. In this paper we employ a multi-isotopic approach utilizing stable carbon, nitrogen, and strontium isotope ratios measured in human skeletal remains from *chullpas* and caves from the sites of Marcacajirca, Ushcugaga, and Jato Viejo, located in the Conchucos region of highland Peru (Fig. 1). Using biogeochemical and bioarchaeological methods we evaluate the nature of diet, geographic origins, and residential mobility at these three sites, and we explore whether LIP peoples were exploiting different altitudinal production zones either directly, or through the establishment of exchange relationships. Additionally, this study addresses questions surrounding the importance of dietary elements, including cultigens such as maize and camelids during the LIP.



**Fig. 1.** Map showing archaeological sites within the study area. Red triangles represent the archaeological sites from which skeletal samples were collected for this project, while black triangles indicate additional archaeological sites mentioned in the text. Map was produced using ArcGIS 10.4, with all subsequent layout and design performed in Photoshop CC 14. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

## 2. Background

### 2.1.1. Stable Carbon and Nitrogen Isotope Analysis

Stable carbon and nitrogen isotope ratios ( $^{13}\text{C}/^{12}\text{C} = \delta^{13}\text{C}$ ,  $^{15}\text{N}/^{14}\text{N} = \delta^{15}\text{N}$ ) in organic tissue largely reflect the kinds of foods consumed during the life of an organism (Ambrose, 1990; DeNiro and Epstein, 1978; Deniro and Epstein, 1981; Deniro and Schoeninger, 1983; Keegan and DeNiro, 1988; Schoeninger et al., 1983; Tieszen and Fagre, 1993; Walker and DeNiro, 1986). A significant source of variation in  $\delta^{13}\text{C}$  values comes from differences in the carbon-fixing photosynthetic pathways of plants (Finucane et al., 2006; Schoeninger, 1985; Schoeninger and Moore, 1992). Many plants found in the Andean highlands utilize the Calvin Cycle ( $\text{C}_3$ ) (i.e., potatoes [*Solanum* sp.] and other tubers, quinoa [*Chenopodium quinoa*], tarwi [*Lupinus mutabilis*], and squash [*Cucurbita* sp.]) and have an average  $\delta^{13}\text{C}$  value of  $-26.5\text{‰}$  (Tieszen and Fagre, 1993; van der Merwe and Medina, 1989). Andean domesticates utilizing the Hatch-Slack pathway ( $\text{C}_4$ ) include such as maize (*Zea mays*), millet, and amaranthus including kiwicha (*Amaranthus caudatus*) and have an average  $\delta^{13}\text{C}$  value of  $-12.5\text{‰}$  (Finucane et al., 2006; Hatch and Slack, 1966; Hatch et al., 1967; van der Merwe and Medina, 1989).

Analysis of the  $\delta^{15}\text{N}$  composition of human collagen has been used to inform on the trophic level of an individual's diet as well as the possible environment in which protein was acquired (Schoeninger and DeNiro, 1984; Walker and DeNiro, 1986). There is a trophic level increase of  $\sim 2\text{--}5\text{‰}$  in  $\delta^{15}\text{N}$  values that allows for the use of  $\delta^{15}\text{N}$  values in reconstructing food webs (Ambrose and DeNiro, 1986; Hedges and Reynard, 2007; Minagawa and Wada, 1984; Schoeller, 1999; Schoeninger and DeNiro, 1984).

### 2.0.1. $^{87}\text{Sr}/^{86}\text{Sr}$ analysis and human mobility

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

Bioavailable strontium (strontium that makes its way into the food chain) often differs from geologically available strontium (Budd et al., 2000; Evans et al., 2010; Price et al., 2002). Thus, it is important to assess the bioavailable  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of a given region by analyzing local flora and fauna (Price et al., 2002). Assuming the consumption of only locally sourced food and water, bioavailable  $^{87}\text{Sr}/^{86}\text{Sr}$  values will primarily reflect the signature of the immediate geological location in which an individual lived during the sampled body tissues formed.

## 3. Materials

The study area is located in the Puccha Basin, which is composed of the Huaritambo, Mosna and Puccha rivers (Fig. 1). Collectively, these rivers form part of the larger Conchucos region, an intermontane valley system situated on the eastern side of the Cordillera Blanca in highland Ancash, and that drains into the upper Marañón River. During the LIP most archaeological sites in this area were positioned at elevations above 3700 masl (Ibarra, 2021), likely reflecting an agropastoral economy. Recent studies of mortuary practices in the region

demonstrate that people were buried in *chullpas*, caves, and in rare interments underneath houses (Ibarra, 2021; Mantha, 2009). Many *chullpas* and caves contained the remains of multiple individuals. These burials were originally wrapped bundles that after deteriorating over time, produced commingled remains of different individuals. In this study, we focus on tombs from three archaeological sites that were radiocarbon dated to the 14th and 15th centuries AD: Marcajirca, Ushcugaga, and Jato Viejo (see Fig. 2; Table S1).

### 3.1. Marcajirca

Marcajirca is located at 3750 masl, approximately 6 km east of the modern-day city of Huarí. Marcajirca is a large settlement covering an area of over 40 ha and composed of residential, funeral and ceremonial sectors (Fig. 3). The residential sector consists of a cluster of approximately 50 houses, with an estimated population of at least 300 residents during the LIP occupation (Ibarra, 2009; Ibarra, 2021).

The mortuary sector lies in the center of the site. It includes 37 *chullpas*, 21 burial caves, and at least 2 below-ground burials situated inside two abandoned houses. Through the analysis of six *chullpas* and caves, we estimate that the *chullpas* held between 36 and 77 individuals, while caves held between 9 and 72 (Table 1) (Ibarra, 2009, Ibarra, 2021). Skeletal analysis of human remains found in both *chullpas* and caves revealed that the bodies were not all interred at the same time but were buried over multiple generations (see Burger et al., 2021). In addition, in both caves and *chullpas* there was a high frequency of cranial trauma documented, presumably caused by interpersonal violence. Archaeological testing of four *chullpas* yielded 24 adult crania, of which eight (33%; 5 male, 1 possible female, 2 indeterminate sex) demonstrated healed or unhealed fractures (Titelbaum et al., 2013).

Two below-ground, multi-interment tombs (Tombs S7 and S10) were identified at Marcajirca. These two contexts are unique as very few below-ground tombs have been documented dating to the LIP within the Conchucos region. Both tombs were found within the interior of two houses, beneath the floor. Unlike other tombs in Marcajirca, these are not associated with architecture and the remains recovered were found just above bedrock. In S7, a minimum of 12 adult and sub-adult individuals were identified. In S10 the articulated remains of a minimum of 48 adult, sub-adult and infants were recovered. Anatomical position suggests these individuals were wrapped in cloth and interred in a flexed position.

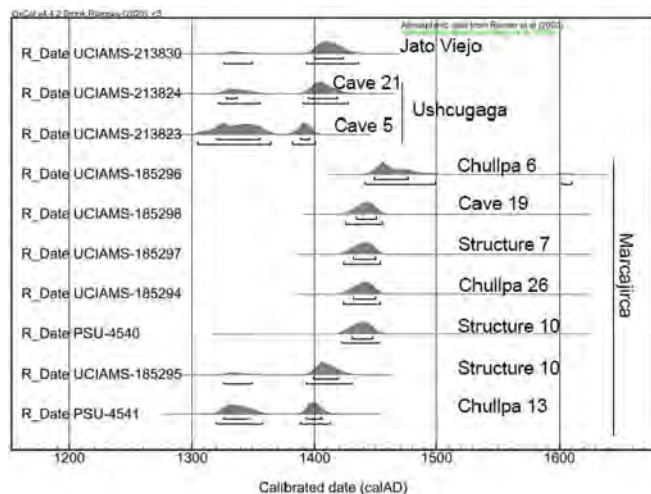


Fig. 2. Calibrated radiocarbon (68.2% and 95.4% confidence intervals) dates from Marcajirca, Ushcugaga and Jato Viejo. Radiocarbon dates were calibrated with the mixed curve (Marsh et al., 2018) using OxCal v. 4.4.2.

### 3.2. Jato Viejo

Jato Viejo is a cave site that contains human burials but does not have an associated residential site (Fig. 3). The closest coeval settlement is Nawpamarca, located about 2 km to the west. Situated at an elevation of 3865 masl, Jato Viejo consists of 14 burial caves scattered along a vertical rock outcrop. Cave 1 contained the skulls of at least 12 individuals, while the other caves only yielded evidence of scattered bone. Samples for the current analysis were collected from Cave 1 (Table 1; Fig. 3).

### 3.3. Ushcugaga

Ushcugaga is an isolated cemetery, located above the Huaritambo River at an altitude of 3500 masl, consisting of a field of boulders covering an area of 1.2 ha (Fig. 3). These boulders had spaces beneath them that were used for burials. Twenty boulder overhangs with human remains were identified during the survey of this site. Field analysis of the human remains determined the presence of one to seven individuals, including adults and sub-adults, in each of the openings (Table 1; Fig. 3).

### 3.4. Human skeletal material

A total of 101 individual human teeth ( $M_1$ ,  $M_2$ , or  $M_3$ ) were collected from Marcajirca, Ushcugaga and Jato Viejo (Table S2). Due to the high degree of commingled remains found at all three archaeological sites, teeth were removed from the skull directly, thus ensuring all teeth collected came from different individuals. Dentine from each tooth was used for  $\delta^{13}C$  and  $\delta^{15}N$  analysis, while only a subset of enamel samples ( $n = 53$  individuals) was used for  $^{87}Sr/^{86}Sr$  analysis.

### 3.5. $\delta^{13}C$ and $\delta^{15}N$ dietary reference material

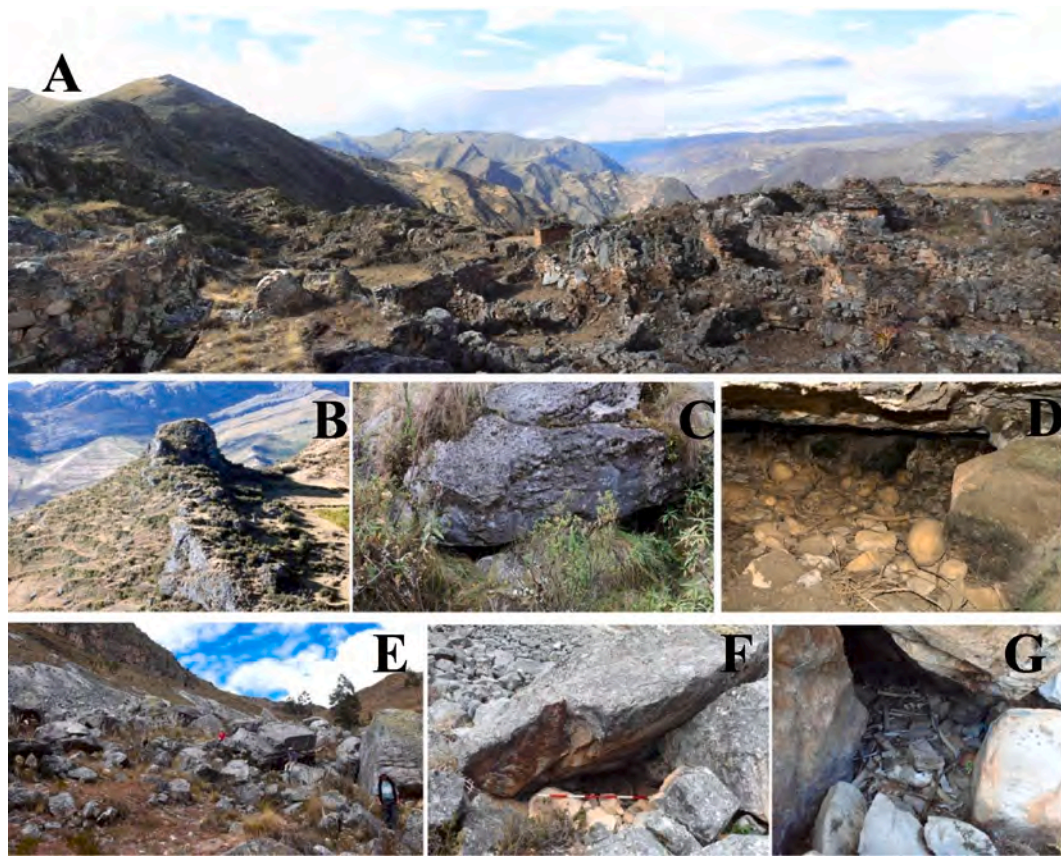
We compiled light stable isotope data from possible dietary resources from the relevant literature (DeNiro and Hastorf, 1985; Finucane et al., 2006; Turner et al., 2010; Washburn et al., 2020) and focused on food types found in the Andean highlands with similar ecological conditions (Washburn et al., 2020). In our study, only modern plant sample data was included from DeNiro and Hastorf (1985).

To eliminate overlap, dietary meat sources were split into groups based on the animal's  $\delta^{13}C$  value (Table 2). Animals with  $\delta^{13}C$  values indicative of a  $C_3$  plant diet ( $< -20\text{‰}$ ) are classified as  $C_3$  plant foddered and/or grazers (i.e., camelids, white-tail deer, and/or taruca). While animals with  $\delta^{13}C$  values within the  $C_4$  range (i.e.,  $< -9\text{‰}$ ) were classified as maize foddered camelids (Finucane et al., 2006), guinea pigs (*Cavia porcellus*) typically have diets that reflect the isotopic signature of the food provided to them, thus they tend to share similar isotope values with humans (Finucane et al., 2006; Washburn et al., 2020). As a result, if combined into one group, guinea pig  $\delta^{13}C$  values would result in a large standard deviation (mean  $\delta^{13}C$  value  $-10.9\text{‰} \pm 3.7$ ). It is for this reason guinea pigs' isotope values were divided into two groups, Group 1: mixed plant diet [ $-18.6\text{‰}$  to  $-14.6\text{‰}$ ] and Group 2:  $C_4$  plant diet [ $-12.6\text{‰}$  to  $-7.0\text{‰}$ ].

### 3.6. Bioavailable $^{87}Sr/^{86}Sr$ isoscape reference material

The Conchucos region is geologically complex, comprised of Mesozoic sedimentary rock formations including sandstones, dark shales, and carbonates (limestone, marls and dolomites), as well as metamorphic rocks like quartzite and shale. The entire region is shaped by folded and uplifted layers of bedrock forming closely stacked geologic formations with differing ages, and  $^{87}Sr/^{86}Sr$  values. These geologic formations run from north to south and are parallel to each other. There is also considerable repetition of specific geologic formations throughout the Conchucos region (Fig. 4). As a result, while there is variation in  $^{87}Sr/^{86}Sr$  values there are also distinct sections of this region where





**Fig. 3.** Photographs taken at Marcajirca, Jato Viejo and Ushcugaga. A) panoramic view from Marcajirca, B-D) Cave structures found at Jato Viejo; C) Modified entrance to Cave 1; D) commingled remains from Cave 1 (MNI = 10; [Table 1](#)), and E-G) Rockslide and cave burials found at Ushcugaga; F) Typical overhang created by rockslide where burials were placed (Average estimated MNI = 1–7 individuals; [Table 1](#)).

**Table 1**

Estimated minimum number of individuals (MNI) and sample size for each burial context.

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

$^{87}\text{Sr}/^{86}\text{Sr}$  values are similar ([Fig. 4](#)). We compare previously published reference data collected from an extensive  $^{87}\text{Sr}/^{86}\text{Sr}$  isoscape mapping project of all major geological formations within 3840 km<sup>2</sup> surrounding the study sites ([Fig. 4](#); [Washburn et al., 2021](#)) with human enamel  $^{87}\text{Sr}/^{86}\text{Sr}$  values in order to gain a comprehensive picture of mobility

**Table 2**

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

Source	N	Mean $\delta^{13}\text{C}$ ‰	1 $\sigma$	Mean $\delta^{15}\text{N}$ ‰	1 $\sigma$
C <sub>3</sub>	45	−26.0	1.5	4.6	2.1
C <sub>4</sub>	13	−11.4	0.5	5.0	2.6
Legumes	41	−25.3	1.3	2.5	1.8
C <sub>4</sub> foddered camelids	11	−10.0	1.4	6.5	1.4
C <sub>3</sub> foddered and/or grazers	10	−18.7	0.8	7.4	1.7
Guinea Pig – Group 1	8	−17.1	1.3	8.3	0.4
Guinea Pig – Group 2	10	−9.4	2.3	8.5	0.9

during the Late Intermediate Period.

#### 4. Methods

We radiocarbon dated ten human bone/tooth samples to establish absolute dates for the burial contexts included in this study (see [supplementary information; Table S1](#)). Further, sex was estimated using morphological observations of the skull ([Buikstra and Ubelaker, 1994](#)). Examined features include the robusticity of muscle attachments on the cranial vault (i.e., nuchal area and the mastoid process), forehead shape, supraorbital ridge, and chin shape (when applicable). The minimum number of individuals (MNI) was calculated based on the duplication of skeletal elements for Marcajirca and Jato Viejo. MNI is useful in this context as all skeletal remains were commingled. When possible, elements were sorted by body side, age, sex and size to estimate the highest MNI present ([Table 1](#)).

For 40 of the 101 individuals, the bioarchaeological assessment of

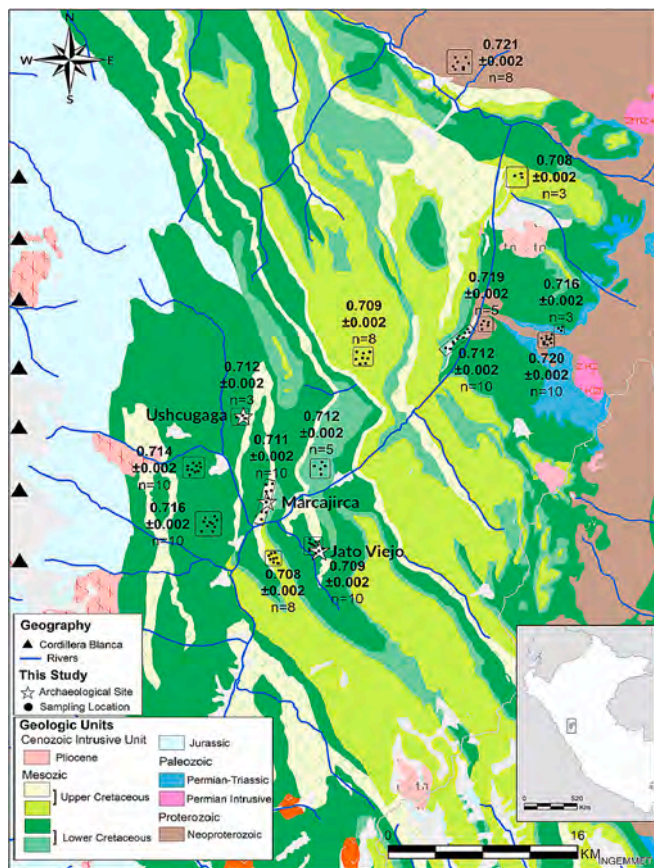


Fig. 4.  $^{87}\text{Sr}/^{86}\text{Sr}$  isoscape of the Conchucos region in the north-central Peruvian highlands referred to in this study (after Washburn et al., 2021). Map was produced using ArcGIS 10.4, with all subsequent layout and design performed in Photoshop CC 14.2.

sex was validated using ancient DNA analysis, validating our bioarchaeological sex estimation for 30 individuals; 2 individuals were shown to have been incorrectly sexed during the original morphological assessment, and the sex of 8 individuals could not be established using aDNA (see [supplementary information, Table S2 and S3](#)).

#### 4.1. Isotope analysis

For the analysis of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , we extracted collagen from human dentin samples following the protocol outlined by Richards and Hedges (1999).  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  analysis was conducted in the UC Santa Cruz Stable Isotope Laboratory using a CE Instruments NC2500 elemental analyzer coupled to a Thermo Finnigan DELTAplus XP isotope ratio mass spectrometer via a Thermo-Finnigan ConFlo III. All measurements are corrected to VPDB (Vienna PeeDee Belemnite) for  $\delta^{13}\text{C}$  and AIR (atmospheric  $\text{N}_2$ ) for  $\delta^{15}\text{N}$  with an analytical error < 0.1‰ for  $\delta^{13}\text{C}$  and < 0.2‰ for  $\delta^{15}\text{N}$  (for more details on these procedures see [supplementary information](#)).

For the analysis of  $^{87}\text{Sr}/^{86}\text{Sr}$ , tooth enamel samples were processed in the UC Santa Cruz W.M. Keck Isotope Laboratory clean room facility. Following the procedure outlined by Deniel and Pin (2001), enamel samples and procedural blanks were subjected to gravity flow column chromatography using Sr-spec<sup>TM</sup> resin and analyzed parallel to the international standard SRM 987 on a Thermo Finnigan Neptune<sup>TM</sup> MC-ICP-MS. See [supplementary information](#) for a detailed description of these sample preparation procedures.

#### 4.2. Determination of local $^{87}\text{Sr}/^{86}\text{Sr}$ ranges

The application of  $^{87}\text{Sr}/^{86}\text{Sr}$  analysis to identify an individual's potential place of origin relies on determining what characterizes “local” vs “non-local” (Price et al., 2002). In our study region this is challenging due to the repetition of the same geologic formations (and hence  $^{87}\text{Sr}/^{86}\text{Sr}$  values) over significant distances (Washburn et al., 2021). Inhabitants of the Conchucos region presumably utilized landscapes within multiple formations, each with differing  $^{87}\text{Sr}/^{86}\text{Sr}$  values, while farming or participating in herding or hunting. In cases such as this, a widespread and systematic survey of each geological formation and their underlying  $^{87}\text{Sr}/^{86}\text{Sr}$  values was crucial.

We use published flora (*Stipa ichu*) and fauna (terrestrial snail shell; Bulimulidae)  $^{87}\text{Sr}/^{86}\text{Sr}$  data from Washburn et al. (2021) to estimate the bioavailable  $^{87}\text{Sr}/^{86}\text{Sr}$  range for 5–8 km<sup>2</sup> surrounding each archaeological site, as shown by the boxes around sampling locations in Fig. 4. The size of the specific sampling area around each archaeological site was variable due to differences in landscape conditions and accessibility because of challenging mountainous terrain. However, we targeted an area that was projected to be large enough to encompass any potential ‘local’ activities such as habitation and farming. For the broader  $^{87}\text{Sr}/^{86}\text{Sr}$  isoscape, in each geological unit we selected sampling locations where anthropogenic contamination was unlikely as there were no signs of use through agriculture and a considerable distance to roads and/or towns (Washburn et al., 2021; see also Bataille and Bowen, 2012; Bentley, 2006; Price et al., 2002). In all sampling locations, individual environmental samples were taken at a minimum of 150 m apart from one another.

We then compared the human enamel  $^{87}\text{Sr}/^{86}\text{Sr}$  values to these local ranges to identify individuals with  $^{87}\text{Sr}/^{86}\text{Sr}$  values falling outside of the estimated local  $^{87}\text{Sr}/^{86}\text{Sr}$  range of where they were buried. Individuals with non-local  $^{87}\text{Sr}/^{86}\text{Sr}$  values were considered as having consumed non-local food sources while their tooth enamel was forming, either by being of non-local origin, or by consuming non-locally produced foods. Whereas individuals with  $^{87}\text{Sr}/^{86}\text{Sr}$  values matching those of the immediate vicinity of each site may have consumed local sources of  $^{87}\text{Sr}/^{86}\text{Sr}$  and were therefore probable residents of that area. Human enamel  $^{87}\text{Sr}/^{86}\text{Sr}$  values were then paired with those found within the broader isoscape. This permitted us to hypothesize potential places of origin for those individuals whose  $^{87}\text{Sr}/^{86}\text{Sr}$  values did not match the geology surrounding the site in which they were buried, while also taking into consideration the potential mixing of  $^{87}\text{Sr}/^{86}\text{Sr}$  values when food resources were acquired from multiple geologies.

#### 4.3. Statistical data analyses

Three linear mixed models were run in R (version 3.6.3, R core team, 2013), each testing for the effects of site, sex and burial type on  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$  ( $n = 101$ ) and  $^{87}\text{Sr}/^{86}\text{Sr}$  ( $n = 53$ ). Models included tooth type as a random effect to control for isotopic differences between teeth forming at different ages (S1).

To assess the proportions of food resources (i.e., C<sub>4</sub>, C<sub>3</sub>, leguminous plants, foddered camelids, grazers, and guinea pigs [group 1 and group 2]) within the diet of individuals, we ran several dietary mixing models separating by site and by sex (see SI for details), using the SIAR package (Stable Isotope Analysis in R, version 4, Parnell et al., 2010). SIAR provides a mixing model for estimating proportional contributions (i.e., 25, 75, and 95% credibility intervals) of different possible food sources in a consumer's diet (Parnell et al., 2010; Koch and Phillips, 2002; Phillips and Koch, 2002; Washburn et al., 2020). In this study, dietary sources were determined to be a staple component in diet if they represented > 25% of the modeled diet (Kennett et al., 2020).



## 5. Results

### 5.1. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data

Atomic C/N ratios were between 2.9 and 3.6 for all samples, suggesting well-preserved tooth collagen (Ambrose and Norr, 1993; DeNiro and Hastorf, 1985). The  $\delta^{13}\text{C}$  values of human collagen from all sites range from  $-17.0\text{‰}$  to  $-12.4\text{‰}$  with an average of  $-14.2\text{‰}$ , whereas the  $\delta^{15}\text{N}$  values range from  $7.7\text{‰}$  to  $11.5\text{‰}$  with an average of  $9.4\text{‰}$  (Table 3; Fig. 5; Table S2). Based on these values, the diets of individuals from Marcacjirca, Jato Viejo and Ushcugaga appear to represent a predominantly  $\text{C}_4$  plant diet supplemented by terrestrial herbivore protein.

The full  $\delta^{13}\text{C}$  model was significant ( $\chi^2 = 36.3$ ,  $\text{df} = 5$ ,  $p < 0.0001$ ), driven by the effect of site ( $p < 0.0001$ ), and the effect of sex ( $p = 0.0394$ ), whereas burial type had no effect. Marcacjirca had on average  $1.5\text{‰}$  higher  $\delta^{13}\text{C}$  values, and Ushcugaga had on average  $2\text{‰}$  higher  $\delta^{13}\text{C}$  values, than the site of Jato Viejo. Males had on average  $0.2\text{‰}$  higher  $\delta^{13}\text{C}$  values than females (Fig. 6) at all three sites. Based on a dietary mixing model, males consumed an average of 4% more  $\text{C}_4$  plants in their diet (3% at Marcacjirca, 5% at Jato Viejo and 4% at Ushcugaga) compared to females at each respective site.

The full  $\delta^{15}\text{N}$  model was significant ( $\chi^2 = 4.0$ ,  $\text{df} = 5$ ,  $p = 0.0155$ ), but here only the predictor of site had an effect ( $p = 0.0077$ ), not sex or burial type. Marcacjirca individuals had on average  $0.2\text{‰}$  lower values than individuals at the site of Jato Viejo, whereas individuals from Ushcugaga had on average  $0.4\text{‰}$  higher  $\delta^{15}\text{N}$  values than individuals from Jato Viejo (Fig. 6). However, compared to the dietary differences reflected in  $\delta^{13}\text{C}$  values, these differences in  $\delta^{15}\text{N}$  are negligible and close to the analytical error.

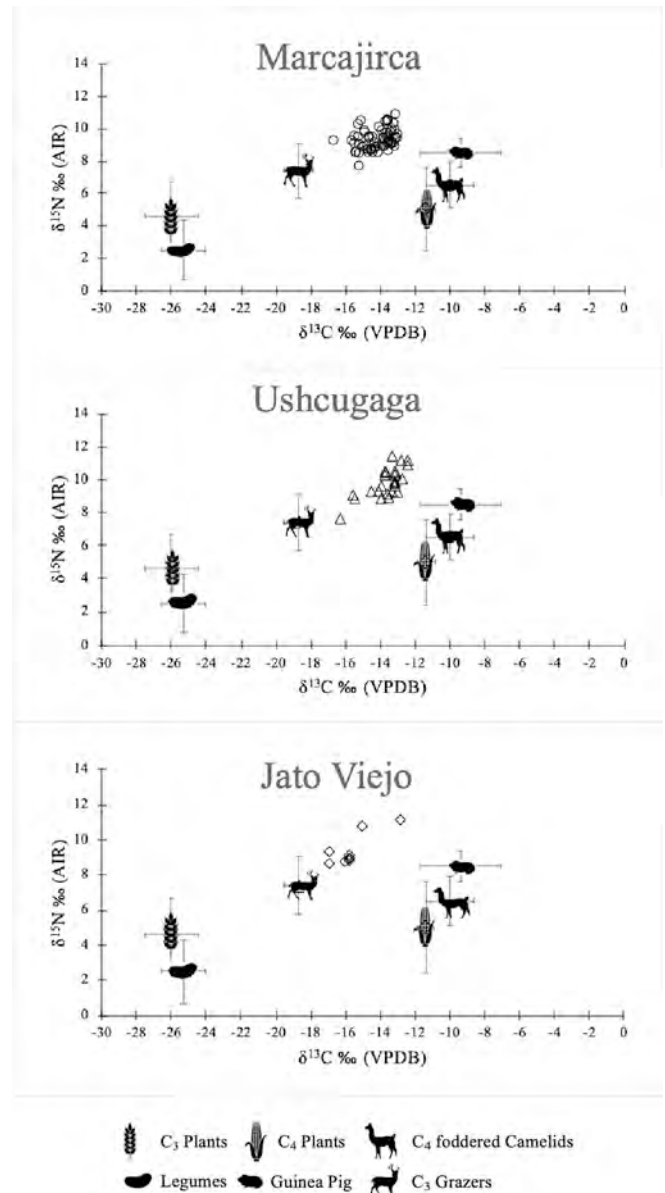
### 5.2. Dietary mixing models

Our dietary mixing model results suggest that the majority of individuals from all three archaeological sites have diets consisting primarily of  $\text{C}_4$  plants, presumably maize. Across all sites we estimate that maize constituted between 25% and 70% (75% credibility interval) of the diet (Fig. 7) and thus represented a staple crop (e.g., Kennett et al., 2020) during the LIP. In addition to maize, diet was further supplemented by terrestrial meat protein (Fig. 7). At all three archaeological sites, our mixing model suggests the consumption of animals that grazed on (or were fed)  $\text{C}_3$  plants (between 0 and 40% [75% credibility interval]), but little to no consumption of  $\text{C}_4$  foddered camelids (Fig. 7). This finding suggests that the individuals included in this study relied on animals (probably domesticated camelids) from the high altitude and  $\text{C}_3$  grass dominated puna (Cadwallader et al., 2012; DeNiro and Hastorf, 1985; Powell and Still, 2009; Samec et al., 2017). We note that the “grazer group” input for the model consists of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of both wild white-tailed deer (*Odocoileus virginianus*) (Sayre et al., 2016; Washburn et al., 2020), and domesticated camelids that grazed on  $\text{C}_3$

**Table 3**

Descriptive statistics for the  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  measurements for individuals from Marcacjirca, Ushcugaga and Jato Viejo.

	Marcacjirca	Ushcugaga	Jato Viejo
$\delta^{13}\text{C}$			
Mean	-14.2	-13.6	-15.7
Std dev. (1 $\sigma$ )	0.81	0.95	1.22
Range (‰)	-16.6 to -13.0	-16.3 to -12.4	-17.0 to -12.8
$\delta^{15}\text{N}$			
Mean	9.3	9.8	9.4
Std dev. (1 $\sigma$ )	0.62	0.87	0.92
Range (‰)	7.9 to 10.9	7.7 to 11.5	8.9 to 11.2
$^{87}\text{Sr}/^{86}\text{Sr}$			
Mean (Human)	0.7115	0.7104	0.7101
Std dev. (1 $\sigma$ )	0.0007	0.0011	0.0004
Human Range	0.7100 to 0.7125	0.7095 to 0.7125	0.7096 to 0.7106
Bioavailable Range	0.7107–0.7116	0.7111–0.7133	0.7092–0.7111



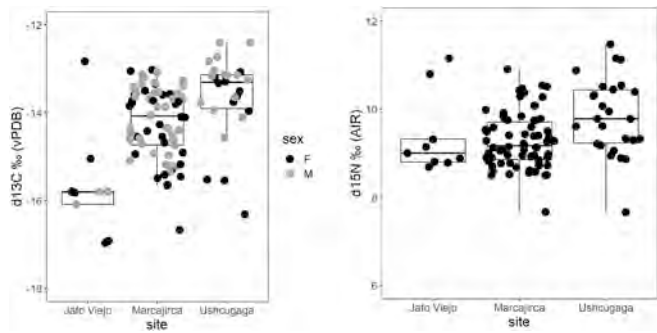
**Fig. 5.** Scatter plots showing the human  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values for the sites of (A) Marcacjirca, (B) Ushcugaga, and (C) Jato Viejo along with mean ( $\pm 1\sigma$ ) isotope values for potential food sources. See Table 2 for the dietary source data used.

grasses (Finucane et al., 2006). The mixing model cannot differentiate between these two species of  $\text{C}_3$  grazers because they have overlapping  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values. Faunal assemblages from the LIP found at sites such as Marcacjirca are dominated by camelid remains. As such, we assume in our model that camelids, rather than wild deer, were a more common source of protein for individuals from these three sites during the LIP.

The results of our model also suggest consumption of guinea pig (*Cavia porcellus*) as an additional source of dietary protein (Fig. 7). As dependent scavengers, guinea pigs have diets that represent the food provided over the lifetime of the animal (Finucane et al., 2006). As a result, the range of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values observed in the reference data collection of guinea pig is relatively large.

### 5.3. $^{87}\text{Sr}/^{86}\text{Sr}$ data

$^{87}\text{Sr}/^{86}\text{Sr}$  values were measured in a representative sample of human



**Fig. 6.**  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  data for human collagen samples by site. Individuals not genetically sexed were determined to be male/female based on skull morphology. A) The effects of both site and sex on the  $\delta^{13}\text{C}$  values were significant. B) The effect of site was significant on the  $\delta^{15}\text{N}$  values, whereas sex had no effect.

dental enamel ( $n = 53$ ) in order to examine patterns of residential mobility. The repeated  $^{87}\text{Sr}/^{86}\text{Sr}$  measurements of the SRM 987 standard resulted in an average value of  $0.7094 \pm 0.00011$ . The procedural blanks were considered negligible, suggesting no sample cross-contamination. Human  $^{87}\text{Sr}/^{86}\text{Sr}$  values from Marcacajirca range from 0.7100 to 0.7125, whereas values from Ushcugaga range from 0.7095 to 0.7125, and values from Jato Viejo range from 0.7096 to 0.7106. The  $^{87}\text{Sr}/^{86}\text{Sr}$  model was significant ( $\chi^2 = 19.4$   $df = 5$ ,  $p = 0.0016$ ), showing the predictor site had a significant effect ( $p = 0.0175$ ), whereas sex and burial type did not. Individuals from the site of Marcacajirca have on average 0.00125 higher values than individuals from the two other sites (Fig. 8).

Based on the estimated bioavailable  $^{87}\text{Sr}/^{86}\text{Sr}$  ranges for all three archaeological sites (Figs. 4 and 9), 42% ( $n = 15/36$ ) of all individuals measured at Marcacajirca can be considered non-local to the site (local

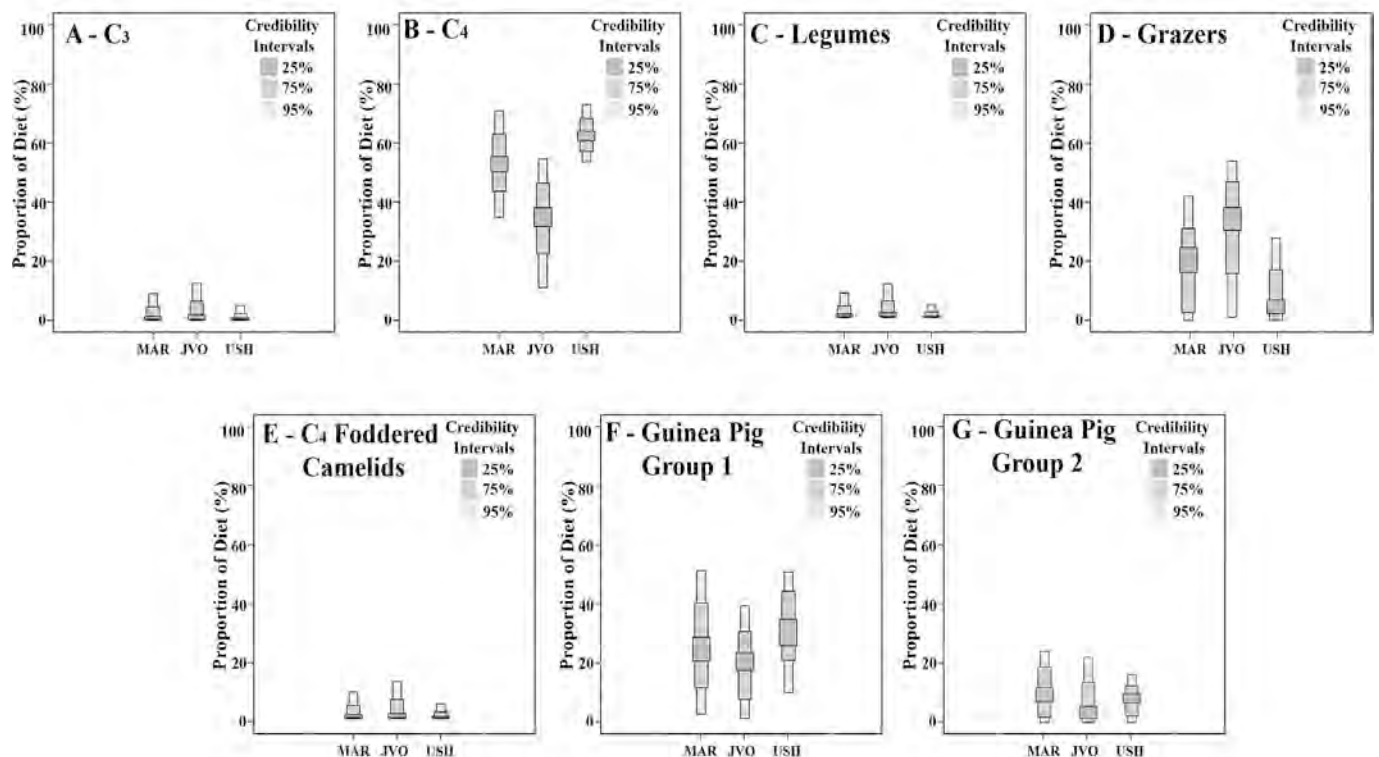
$^{87}\text{Sr}/^{86}\text{Sr}$  range at Marcacajirca = 0.7107–0.7116), but likely from somewhere in the larger Conchucos region (Fig. 9A). Most of the non-local individuals found at Marcacajirca are from Structure 10, where 90% ( $n = 9/10$ ) have non-local  $^{87}\text{Sr}/^{86}\text{Sr}$  values (Fig. 4). At Ushcugaga, 80% ( $n = 8/10$ ) of individuals have  $^{87}\text{Sr}/^{86}\text{Sr}$  values outside the established bioavailable local range (local  $^{87}\text{Sr}/^{86}\text{Sr}$  range Ushcugaga = 0.7111–0.7133) (Fig. 9B). In contrast, all individuals found at Jato Viejo can be characterized as local to the site's geological region (local  $^{87}\text{Sr}/^{86}\text{Sr}$  range Jato Viejo = 0.7092–0.7111) (Fig. 9C).

## 6. Discussion

### 6.1. Diet during the LIP

Light isotope data suggests that the individuals buried at Marcacajirca, Ushcugaga, and Jato Viejo relied on maize and camelids as dietary staples, as well as lower quantities of  $\text{C}_3$  plants and guinea pig. Based on dietary mixing models,  $\text{C}_4$  plants played a significant, but varied, role in the diet at each site, comprising 25–70% (75% credibility interval) of the total food consumed (Marcacajirca 40–65%; Ushcugaga 60–70%; and Jato Viejo 25–45%). On average, males consumed  $\sim 4\%$  more maize than females (Fig. 6A). These relatively small differences suggest that maize consumption did not vary significantly between the sexes. This pattern of relative equal consumption of maize has been documented elsewhere in highland Peru during the Late Intermediate Period (Hastorf, 1991).

Variation in the dietary contribution from  $\text{C}_4$  plants at each site indicates differing subsistence strategies that were likely based on site location and access to specific resources. For example, Jato Viejo, the site for which we documented the lowest degree of maize consumption, is also the furthest away from areas suitable for maize farming. The data would suggest that these people either lived, or spent most of their time, in the high-altitude *puna* grassland. In the Peruvian highlands, the upper limit of effective maize cultivation is approximately 3400 masl



**Fig. 7.** Results of several dietary mixing models on human diet for the sites of Marcacajirca, Ushcugaga, and Jato Viejo shown for the seven main potential food resources in the region. 25, 75 and 95% credibility intervals are plotted for each burial context (see Table S2 detailed description of each tomb context).

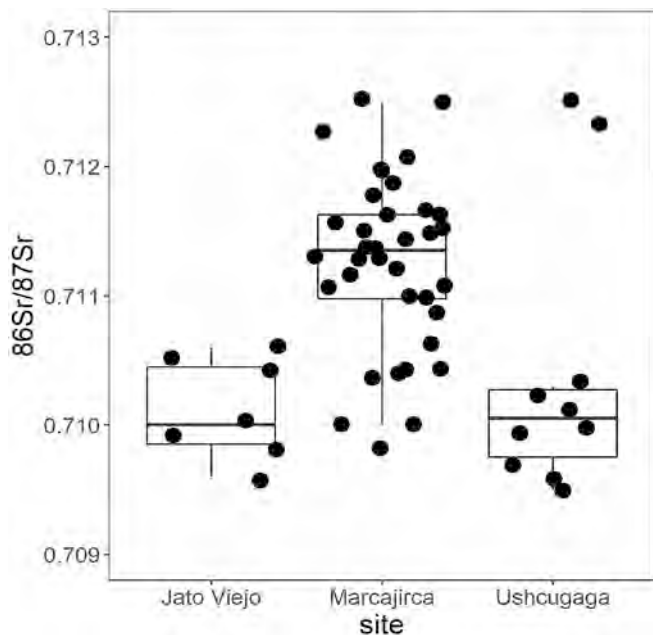


Fig. 8. Significant differences in human  $^{86}\text{Sr}/^{87}\text{Sr}$  values between the three archaeological sites.

(Moseley, 2001: 31). Because the three study sites discussed in this paper are all situated above 3500 masl, the consumption of maize among these populations suggests that people either moved to lower elevation zones for farming, and/or they established exchange relationships with people living in lower altitude areas to acquire maize. Patterns of maize consumption in the Conchucos region are broadly similar to other parts of the highland Andes during the LIP (e.g., Barberena et al., 2020; Burger et al., 2003; Hastorf, 1990, 1991; Hastorf and Johannessen, 1993; Lofaro

et al., 2018; Ratto et al., 2020; Turner et al., 2018).

Our data indicate that while a dietary staple, maize was not the only crop consumed during the LIP in Conchucos. The results of our dietary mixing model suggest a low proportion of the primary consumption of  $\text{C}_3$  plants ( $\leq 10\%$  at Marcacajirca and Ushcugaga and  $\leq 15\%$  at Jato Viejo, 75% credibility interval). This low proportion of purely  $\text{C}_3$  plants in the diets of individuals at all three archaeological sites is surprising given that  $\text{C}_3$  plants comprise most of the cultigens consumed in the highlands, including potatoes, other tubers and quinoa (Hastorf, 1990; Hastorf and Johannessen, 1993). Furthermore, isotopic analyses from some LIP sites in highland Peru also highlight the importance of  $\text{C}_3$  plants to the diet (Toyne et al., 2017; Toyne et al., 2020).

$\delta^{15}\text{N}$  values demonstrates that the diet also included terrestrial animal protein, consistent with the consumption of terrestrial grazers and guinea pig. Though it is isotopically difficult to distinguish between deer and camelids, other archaeological evidence suggests that the LIP inhabitants of Conchucos relied on domesticated camelids. Zooarchaeological data show that after 800/750 BCE, domesticated camelid (llamas and alpacas) herding replaced the hunting of wild camelids (vicuñas and guanacos) and deer in the north-central highlands (Miller and Burger, 1995; Rosenfeld and Sayre, 2016; Uzawa, 2010), a pattern that continued into later times in the north-central highlands (Lau, 2007, 2021). Our data suggest that grazers were eating  $\text{C}_3$  plants (up to 70%; 75% credibility interval), rather than maize fodder, indicating that they were likely herded/pastured in the high-elevation *puna* grasslands, where  $\text{C}_4$  plants like maize cannot be cultivated.

$\delta^{15}\text{N}$  data also point to guinea pig as an additional dietary resource ( $\leq 10\%$  of diet of individuals at each site). Numerous guinea pig bones were recovered from *chullpas* and caves in Marcacajirca that were deposited as offerings (Ibarra, 2021). Ethnographic and archaeological research describe guinea pigs as a feast food that was typically consumed during certain parts of the year (Bolton, 1979; Gade, 1967; Rosenfeld, 2008). Based on ethnographic research within a highland Andean community, Bolton (1979: 240) estimated that guinea pig

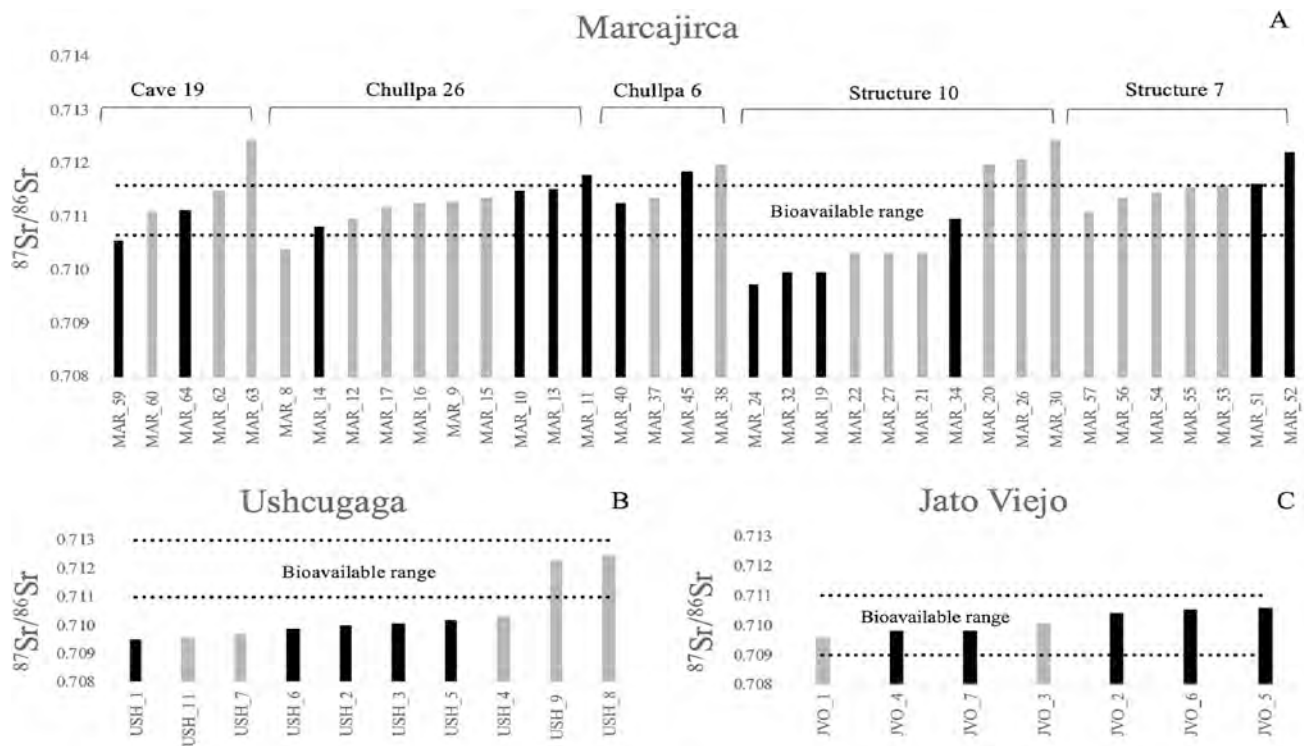


Fig. 9. Barplots showing  $^{87}\text{Sr}/^{86}\text{Sr}$  values of human tooth enamel from (A) Marcacajirca, (B) Ushcugaga and (C) Jato Viejo by sex (males in grey, females in black). Dashed lines represent the upper and lower limits of the calculated bioavailable  $^{87}\text{Sr}/^{86}\text{Sr}$  range for each site based on environmental  $^{87}\text{Sr}/^{86}\text{Sr}$  data for the region (Washburn et al., in 2021).



constituted 3–4% of protein. Our results also suggest that guinea pig was not a dietary staple but was consumed in comparable amounts in the Conchucos during the LIP.

In sum, while there is some individual variation,  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values indicate broadly similar diets between individuals buried at Marcajirca, Ushcugaga and Jato Viejo. Collectively, the dietary information shows that both maize and probably  $\text{C}_3$  plant foddered and/or grazing camelids comprised major components of the diet. Evidence for exploitation and consumption of camelids that were eating  $\text{C}_3$  plant fodder suggest that the individuals examined in this study practiced camelid herding in the *puna* grasslands at elevations above 3500 masl. The surprising lack of purely  $\text{C}_3$  plants in the modeled diet of the individuals studied can likely be attributed to the consumption of protein from animals that relied heavily on  $\text{C}_3$  plants. Additionally, as maize is cultivated in this region at elevations lower than 3400 masl, well below most LIP settlements, we suggest that the LIP groups living in the Conchucos region practiced a form of ecological complementarity (Murra, 1972, 1985), where people either established exchange networks with people living at lower elevations or had direct access to low elevation (under 3400 masl) maize fields through extensive and regular local mobility.

## 6.2. Mobility during the LIP

In Conchucos there are considerable differences in the mean  $^{87}\text{Sr}/^{86}\text{Sr}$  values between geological formations within relatively short distances (Fig. 4). These values range from as low as 0.7081 to as high as 0.7212 (Fig. 4; Washburn et al., 2021). Based on these results, the entire range of observed human values in this study ( $n = 53$ ; 0.7096–0.7125) are consistent with  $^{87}\text{Sr}/^{86}\text{Sr}$  values within the Conchucos region, suggesting individual mobility during the LIP was largely restricted to within this valley system. However, there are equifinality problems (Price et al., 2007) in the Andes with similar isotope values occurring over much larger geographic regions than encompassed in the isoscape used in this study (Price et al., 2007; Scaffidi and Knudson, 2020; Washburn et al., 2021). For instance,  $^{87}\text{Sr}/^{86}\text{Sr}$  similar values to those we observed in our study area were also recorded at much more distant localities in other parts of coastal and highland Peru (Scaffidi and Knudson, 2020; see Andrushko et al., 2009; Conlee et al., 2009; Knudson

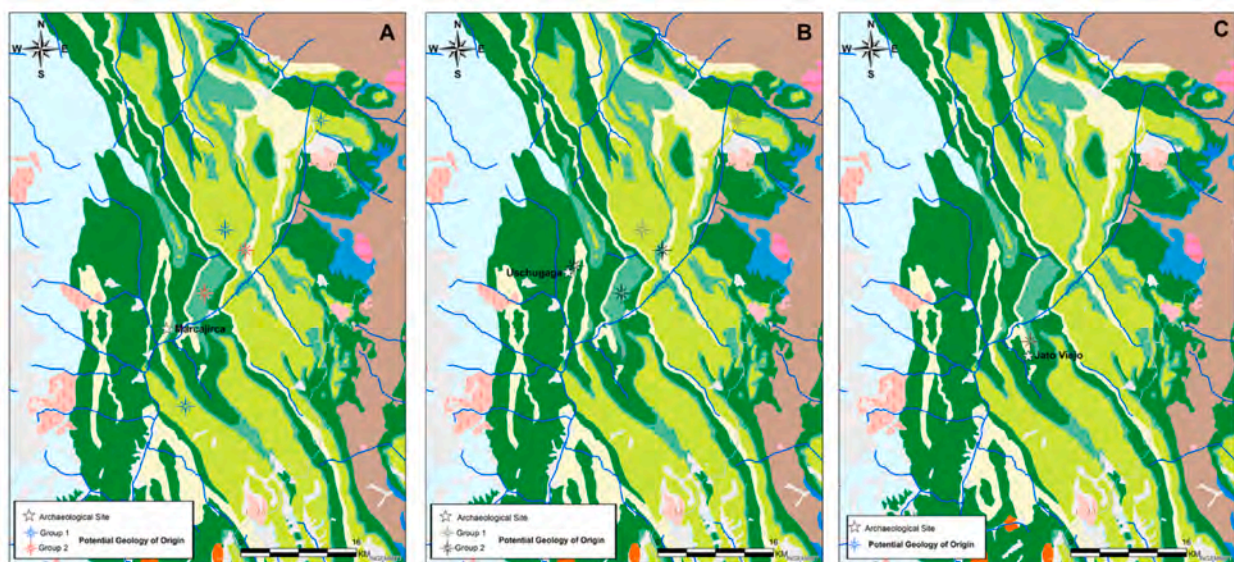
and Torres-Rouff, 2009; Knudson and Price, 2007; Tung and Knudson, 2018; Slovak et al., 2009; Slovak et al., 2018; Turner et al., 2009). An earlier study of Recuay (c. 1–700 CE) burials at Chavín de Huántar (a site located in our study area) identified two non-local individuals. The authors suggested long-distance migration into the region, however, these  $^{87}\text{Sr}/^{86}\text{Sr}$  values also overlap with those now known from the Conchucos region (Slovak et al., 2018; Washburn et al., 2021).

Based on this study, it is possible that during the LIP non-local individuals migrated into the Conchucos region from more distant locales. Based on our published isoscape data (Washburn et al., 2021) and other lines of archaeological evidence, we suggest that mobility was largely restricted to the Conchucos region of the north-central highlands during the LIP. The LIP sites discussed in this paper have an absence of indicators for extensive interaction networks such as foreign pottery styles from other areas of the Andes (Ibarra, 2021). Instead, Fig. 10 presents our hypothesized, localized isotopic catchment areas for Marcajirca, Ushcugaga and Jato Viejo.

### 6.2.1. Marcajirca

In the case of Marcajirca, 58% ( $n = 21$ ) of all individuals tested have local  $^{87}\text{Sr}/^{86}\text{Sr}$  values suggesting the individuals were born and raised in the area immediately surrounding the settlement (Fig. 9A). Both *chullpas* and caves exhibit a pattern of locality in which the majority of all sampled individuals have homogenous local  $^{87}\text{Sr}/^{86}\text{Sr}$  values. In Cave 19, 60% of individuals ( $n = 3/5$ ) have similar local  $^{87}\text{Sr}/^{86}\text{Sr}$  values. In *Chullpas* 6 and 26, 80% ( $n = 11/14$ ) human  $^{87}\text{Sr}/^{86}\text{Sr}$  values fall within the bioavailable  $^{87}\text{Sr}/^{86}\text{Sr}$  range surrounding Marcajirca (Fig. 9A). The finding that most individuals from *chullpas* and caves were probably from the same region supports the notion that individuals buried in *chullpas* and caves at Marcajirca might have been members of the same communities, and/or related through kinship (Ibarra, 2021; Titelbaum et al., 2015; Titelbaum et al., 2021).

A contrasting pattern of residential mobility at Marcajirca is exhibited in the below-ground burials of Structures 7 and 10 (Fig. 9A). These two burial contexts are unique as this practice was not common in the highlands during the LIP (Ibarra, 2021; Mantha, 2009; Toohey et al., 2016). In addition, unlike the other burial structures found at Marcajirca, no grave goods or offerings were found in association with either Structure 7 or 10. Radiocarbon dates of multiple individuals within each



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**Fig. 10.** Potential geology of origin for individuals with  $^{87}\text{Sr}/^{86}\text{Sr}$  values outside the established bioavailable ranges for Marcajirca (A), Ushcugaga (B), and Jato Viejo (C). For each archaeological site, individuals were grouped based on their  $^{87}\text{Sr}/^{86}\text{Sr}$  values. Each formation with  $^{87}\text{Sr}/^{86}\text{Sr}$  values matching those found in the sampled human remains were identified as potential formations of origin.

below-ground burial suggest that individuals were placed around the same time, or even as a result of a singular event.

Most individuals buried in Structure 7 ( $n = 6$  local;  $n = 1$  non-local) have  $^{87}\text{Sr}/^{86}\text{Sr}$  values falling within the local bioavailable range of Marcajirca, whereas Structure 10 contains only one female with a local  $^{87}\text{Sr}/^{86}\text{Sr}$  value, while the other nine individuals ( $n = 6$  males, 3 females) have  $^{87}\text{Sr}/^{86}\text{Sr}$  values that are non-local to the site. Among these non-local individuals, two groupings emerge based on their  $^{87}\text{Sr}/^{86}\text{Sr}$  values (Group 1 = 0.7098–0.7104 and Group 2 = 0.7120–0.7125), suggesting that this tomb was used by two groups coming from separate regions (presumably east of Marcajirca) but still within the broader Conchucos area (Fig. 10A). Based on our projected isotope catchment zone, we suggest that individuals from Group 1 may have migrated from a maximum distance of 35 km, while individuals from Group 2 may have originated from within a 15 km range around Marcajirca. Questions remain about the function of the two below-ground burials, as well as the connection between the non-local individuals found in Structure 10 and the larger population at Marcajirca.

### 6.2.2. Ushcugaga and Jato Viejo

In contrast to Marcajirca, Jato Viejo and Ushcugaga are exclusively cave burial cemeteries. At Ushcugaga, human enamel  $^{87}\text{Sr}/^{86}\text{Sr}$  values fall within two distinct groups. Group 1 is made up of the majority ( $n = 10$ ; 80%) of individuals that all have non-local  $^{87}\text{Sr}/^{86}\text{Sr}$  values (Fig. 9B). Based on the homogeneity of values, these individuals likely originated from the same community (possibly within 40 km east of Ushcugaga) and were brought to the cemetery for burial. Group 2 is comprised of two individuals with  $^{87}\text{Sr}/^{86}\text{Sr}$  values that are within the estimated  $^{87}\text{Sr}/^{86}\text{Sr}$  range for Ushcugaga. This suggests that either there is a yet to be identified residential component to Ushcugaga, or these individuals were brought to the site for burial from within a short distance (i.e., within 15 km) of the cemetery (Fig. 10B).

Based on  $^{87}\text{Sr}/^{86}\text{Sr}$  values from environmental reference samples from within the immediate vicinity of Jato Viejo, all individuals sampled ( $n = 7$ ) could be considered to have resided in proximity to the burial site (i.e., within <20 km; Fig. 9C). The closest documented coeval settlement is that of Ñawpamarca, situated 2 km west of Jato Viejo. This archaeological site is found within the same geological formation as Jato Viejo (Fig. 10C); our data suggest that the individuals buried at Jato Viejo may have in fact been residents of this site.

## 7. Conclusions

In the Central Andes, the LIP is traditionally discussed as a time of political instability and fragmentation, with groups moving their settlements to higher altitudes for defensive purposes. This model presents a picture of groups of people in isolation from one another, with potentially limited interaction. However, the location of these archaeological sites seemed to have served multiple functions, including providing access to multiple ecological zones for subsistence, as well as the potential for defensible space under social and political economic conditions where this may have been necessary.

This study demonstrates that the people buried in *chullpas* and caves largely correspond to people from related local communities, which may correspond to extended kin groups. In this respect, our study complements a recent isotopic study of *chullpa* burials from the Chachapoyas region (Toyne et al., 2017). The high proportion of non-local individuals in the below-ground burials at Marcajirca remain a question that will need to be evaluated through future investigation.

The Conchucos region archaeological sites like Marcajirca, Ushcugaga and Jato Viejo were positioned in locations with strategic access to the high-altitude *puna* grassland that was ideal for grazing domesticated camelid herds. At the same time, these high-altitude sites are situated above the elevation boundary for other important agricultural crops. The high proportion of  $\text{C}_4$  plants and grazing terrestrial animal protein in the diet of individuals interred at Marcajirca, Ushcugaga and Jato

Viejo indicate that these populations were utilizing a form of ecological complementarity where people either established exchange relationships, or directly accessed lower elevation agricultural fields through regular movement up and down highland mountain systems. As a result of the closely packed geologic variation within the Conchucos, as individuals moved throughout the landscape to gain access to food resources or acquired food stuffs from other sites throughout the Conchucos, they would have crossed or accessed resources from multiple geologic formations. This indicates connections between different ecological production zones that may be indicative of the establishment/continuation of ethnic communities across the landscape.

Our data adds to an emerging picture obtained from other isotopic studies that show limited evidence for long-distance migration during the LIP (e.g., Andrushko et al., 2009; Lofaro et al., 2018; Scaffidi and Knudson, 2020; c.f. Barberena et al., 2020). Our study suggests that mobility was largely restricted to a local catchment region within the Conchucos region that may not have exceed 40 km, an interpretation that was significantly bolstered by a detailed local isoscape of the region (Washburn et al., 2021).

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jasrep.2021.103291>.

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