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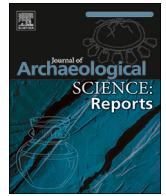Washburn, Eden
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Maize and dietary change in early Peruvian civilization: Isotopic evidence from the Late Preceramic Period/Initial Period site of La Galgada, Peru

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ABSTRACT

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

1. Introduction

The Late Preceramic Period (c. 3000–1700 cal BCE) is of crucial importance to understanding the development of sociopolitical complexity in the Central Andes. Beginning in the early half of the third millennium BCE, different cultures living along the Peruvian coast and adjacent highlands initiated the construction of early traditions of monumental public architecture, which were associated with permanent settlements (Burger, 1992; Pozorski and Pozorski, 2018a; Quilter, 1991; Solis et al., 2001). This pattern continued into the Initial period (1700–800 cal BCE), with a significant proliferation of monumental centers, as well as the introduction of pottery technology (Burger, 1992; Pozorski and Pozorski, 2018a). Furthermore, the Late Preceramic Period and early part of the Initial Period also underwent significant

changes to the subsistence economy, with a growing reliance on cultigens like squash (Cucurbitaceae), beans (Fabaceae), manioc (*Manihot esculenta*), potatoes (*Solanum tuberosum*), and quinoa (*Chenopodium quinoa*), as well as wild game (Beresford-Jones et al., 2018; Caramanica et al., 2018; Coutts et al., 2011; Dillehay et al., 2005, 2007; Duncan et al., 2009; Moseley, 1975; Nesbitt, 2016; Perry et al., 2006; Pozorski, 1979, 1983; Pozorski and Pozorski, 1979; Quilter et al., 1991; Rumold and Aldenderfer, 2016; Weir et al., 1988).

Nevertheless, some scholars have argued that one specific cultigen – maize (*Zea mays*) – played an instrumental role in stimulating the development of early Central Andean complexity (e.g. Bonavia, 2008; Bonavia and Grobman, 1989; Haas et al., 2013; Kistler et al., 2018; Wilson, 1981; Benz and Staller, 2006; Kidder and Lumbreras, 1963; Norr, 1995). However, the growing archaeological record for the Late

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Preceramic Period and Initial Period indicate that while consumed, maize was not an important crop in Peru until after c. 800 cal BCE (Blake, 2015; Staller et al., 2006; Burger, 2012; Burger and Van der Merwe, 1990; Pezo-Lanfranco et al., 2015; Pozorski and Pozorski, 1979, 2006; Seki and Yoneda, 2005; Shady, 2006; Tykot et al., 2006). The use of stable isotope analysis (δ^{13}C and δ^{15}N) has the potential to elucidate these potential changes in diet, as well as determine the specific contribution of different foods, including maize, within an individual's diet.

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

2. Background

2.1. Changes in subsistence practices through time

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

Major highland centers are found in a diverse range of environmental zones. Examples of Late Preceramic Period highland centers include Kotosh (2000 masl) (Izumi and Sono, 1963; Izumi and Terada, 1972), in the Huallaga Drainage, Piruru (3800 masl) in the Alto Marañon (Bonnier, 1997), Huaricoto (2500 masl) (Burger and Salazar-Burger, 1980, 1985, 1986), Hualcayán (3150 masl) (Bria, 2017), and Tumshucaico (2300 masl) (Bueno Mendoza, 2004) in the Callejón de Huaylas, and La Galgada (1100 masl) (Grieder and Bueno Mendoza, 1985; 1988) in the Tablachaca River Valley (Fig. 1). Despite the distances separating them, these Late Preceramic religious centers share key architectural similarities referred to as the Kotosh Religious Tradition (Burger and Salazar, 1980). While much is known about the architecture and religious practices of these highland peoples, less visible aspects of individual life histories including subsistence practices and the varied reliance on available food resources remains unclear.

Late Preceramic Period coastal and highland communities of the north-central Andes relied on mixed economies, including domesticated cultivars that were supplemented by hunting and fishing (e.g. Burger and Van der Merwe, 1990; Quilter et al., 1991). Plant domestication in coastal communities began by c. 8500 years ago with crops like squash, peanuts, beans, manioc and chili peppers (Dillehay et al., 2007; Pearsall, 2008; Perry et al., 2007; Piperno, 2011; Piperno and Dillehay, 2008). Maize was present on the coast by at least 6500BCE (Grobman et al., 2012) and has been found in the form of macrobotanical and microbotanical remains at Late Preceramic centers on the coast (Haas and Creamer, 2004; Haas et al., 2013; Shady, 2006). In the highlands, the use of cultigens also begins relatively early, with an emphasis on species that are well adapted to high altitude habitats like potato, oca (*Oxalis tuberosa*), diverse leguminous plants, and quinoa (Burger and Van der Merwe, 1990; Rumold and Aldenderfer, 2016). Botanical findings at Guitarrero Cave (Lynch, 1980) and Hualcayán (Bria, 2017: 521), and isotopic studies from the Callejón de Huaylas in the north-central highlands (Burger and Van der Merwe, 1990) indicate that maize was also present in the highlands around this time. There is also evidence of maize during the Late Preceramic Period in the south-central highlands (Perry et al., 2006). However, the significance of maize as a dietary resource remains unclear. At this time, animal proteins were likely derived largely from deer, but camelids and small game would have been additional food sources (Burger, 1992; Miller and Burger, 1995; Miller, 1984; Sawyer, 1985; Shimada, 1982; Uzawa, 2010; Wing, 1972, 1978).

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

2.2. The site of La Galgada

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

La Galgada was founded in the mid-to-late third millennium BCE and consists of two large mounds (Grieder et al., 1988). Excavations of the larger of these two mounds revealed a sequence of ceremonial chambers, each with a central fire pit (Grieder and Bueno Mendoza, 1985; Grieder et al., 1988) following architectural conventions of what is known as the Kotosh Religious Tradition (Burger and Burger, 1980). The excavations at the site indicate that it was occupied into the Initial Period when it was abandoned around 1300 BCE.

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

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

2.3. Reconstructing past diets through stable isotope analysis

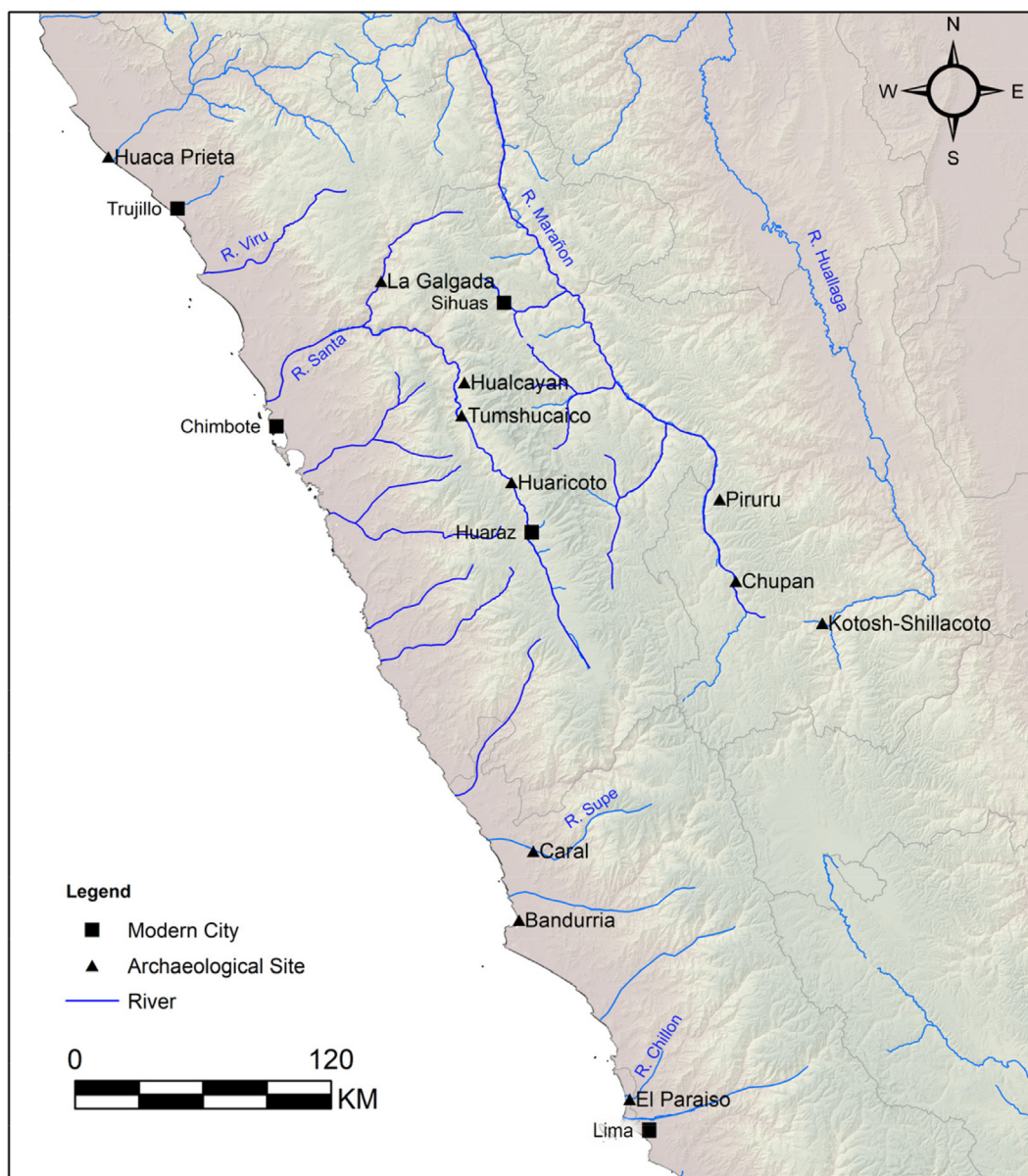This study utilizes the analysis of stable isotope ratios of carbon

Fig. 1. Map of Peru with the location of La Galgada and other sites mentioned in the text.

(δ^{13}C) and nitrogen (δ^{15}N) in human and faunal remains to reconstruct the diets of the past populations interred at the site of La Galgada. Based on previous research conducted at La Galgada, the large number of macrobotanical remains analyzed and the lack of faunal remains suggest that the diets of Late Preceramic and Initial Period individuals should exhibit δ^{13}C and δ^{15}N values that reflect a primarily plant based (C$_3$ and legumes) diet with limited amounts of terrestrial or marine and/or freshwater based protein.

The fundamental variation in values of δ^{13}C in terrestrial food webs stems from differences in the photosynthetic pathways of plants (Finucane et al., 2006; Schoeninger and Moore, 1992). The majority of plants, including those in the Central Andes, utilize the Calvin Cycle (C$_3$) and have an average δ^{13}C value of −26.5‰ (Tieszen and Fagre, 1993; Van der Merwe and Medina, 1989). However, many grasses native to hot, arid environments, including domesticates such as maize, millet, amaranthus (kiwicha) and sugarcane rely on the Hatch-Slack pathway (C$_4$) and can be identified by their substantially higher δ^{13}C values, averaging around −12.5‰ (Finucane et al., 2006; Van der Merwe and Medina, 1989). Plants utilizing the third photosynthetic pathway (CAM), such as succulents (i.e. prickly pears) have

intermediate δ^{13}C values.

Compared to C$_3$ plants, wild C$_4$ plants are rare in the Andes (Powell and Still, 2009). Therefore, any δ^{13}C value indicating a reliance on C$_4$ plants is commonly used to suggest the consumption of maize (Burger and Van der Merwe, 1990; D'Altroy, 2001; D'Altroy and Schreiber, 2004; Finucane et al., 2006, Finucane, 2007, 2009; Goldstein, 2003; Hastorf, 1991; Kellner and Schoeninger, 2008; Slovak et al., 2009; Slovak and Paytan, 2011; Tung et al., 2016; Tung and Knudson, 2018; Tykot et al., 2006; Wilson et al., 2007). However, higher δ^{13}C values might also suggest a reliance on animals which consumed maize or other C$_4$ grasses (Cadwallader et al., 2012), a distinction not commonly addressed. In addition, the distribution of wild C$_4$ grasses throughout the Andes may be underrepresented in the literature, especially in dietary studies which focus primarily on those plants that are edible by humans.

Analysis of δ^{15}N values provides information on past diets by discriminating between non-leguminous plants, leguminous (N-fixing) plants and higher tropic level foods, such as animal protein (Schoeninger and DeNiro, 1984; Walker and DeNiro, 1986). With each step up the food chain there is a tropic level ~3‰ increase in the δ^{15}N

Table 1
List of tombs from La Galgada and number of sampled burials (Grieder et al., 1988).

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

Fig. 2. Dietary source data compiled from DeNiro and Hastorf (1985); Finucane et al. (2006); Turner et al. (2010). Deer excavated from archaeological site of Canchas Uckro and analyzed for this project.

values (Schoeninger and DeNiro, 1984). This tropic level effect is particularly evident in the highly complex food webs typical of aquatic habitats, such as in marine or freshwater fish (Ambrose and Norr, 1993). Due to the absence of fish bones and mollusk remains in the archaeological assemblage at La Galgada, the presence of $\delta^{15}N$ values suggesting a heavy reliance on marine resources is unlikely.

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

3. Materials

At La Galgada, 16 tombs were excavated by Grieder and colleagues (Grieder et al., 1988). Nine of these tombs contained multiple individuals (~3–27 individuals) (Table 1). Bone and teeth (M_2 and M_3) were sampled from 32 individuals (distributed between the nine tombs in which multiple individuals were identified) at the *Museo Nacional de Arqueología, Antropología, e Historia del Perú*, Lima, where the archaeological materials from La Galgada are currently curated. The majority of tombs were looted and in most cases the burials were not completely intact and/or commingled, leaving analysis of skeletal remains difficult (Grieder et al., 1988).

Isotope data from possible dietary resources was compiled from the available literature (DeNiro and Hastorf, 1985; Finucane et al., 2006; Turner et al., 2010) and dietary data was limited to food types found in highland sites with similar ecological conditions as at La Galgada (Table A1). In our model, only modern plant samples were included from DeNiro and colleagues (1985) and as a result, are likely exposed to at least minimal amounts of either manuring or modern fertilizer. The effect of manuring on plants can result in substantial changes in $\delta^{15}N$ values, while modern fertilizer can either raise or lower $\delta^{15}N$ values (DeNiro and Hastorf, 1985; Szpak et al., 2012). There are, however, no statistical or analytical means of detecting this in our mixing model. As a result, we consider the plants included in our mixing model to represent different levels of manuring and fertilization.

In addition, as there has been no extensive isotopic study of wild deer found throughout the Andes, four white-tailed deer (*Odocoileus virginianus*) found at the highland site of Canchas Uckro (c. 1100–800 cal BCE), approximately 120 km south of La Galgada, were analyzed and included in this study (Fig. 1, Table A2).

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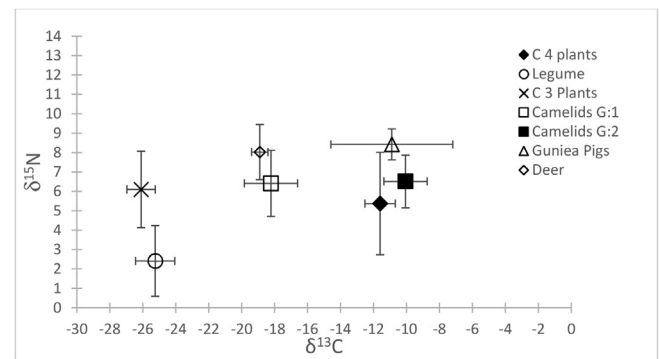
on puna pasture characterized by C_3 vegetation, and the feeding of C_4 plants (maize). For our dietary mixing model, camelid $\delta^{13}C$ and $\delta^{15}N$ values were split into two groups depending on their carbon isotope value (i.e. Group 1: C_3 plant grazers; Group 2: foddered). Guinea pigs have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

4. Methods

4.1. Radiocarbon dates

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

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

4.2. Stable isotope analysis

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

for 24 h to remove humic contaminants. Samples were again rinsed with dH$_2$O (×3), immersed in 1.5 ml pH ≈ 3 dH$_2$O, and placed in an oven at 70 °C for 48 h to solubilize the collagen. The liquid fraction was then removed and transferred to a clean 1.5 ml Eppendorf tube. Samples were filtered using eeze^{TM} filters (60–90 μm) to remove any remaining solid particles, and the liquid fraction was freeze-dried.

The four deer samples were prepared following a modified protocol by Richards and Hedges (1999). Samples were demineralized using 0.5 M HCL, rinsed 3x with dH$_2$O. pH ≈ 3 water was added to each sample and samples were placed in heater blocks at 70 °C for 48 h. Following collagen solubilization, remaining particles were filtered using eeze^{TM} filters (60–90 μm). Samples were then subjected to ultracentrifugation using AMICON Ultra-4 filters with a 30 kDa cutoff and freeze dried. Only the large fraction of collagen (i.e. > 30 kDa) was analyzed.

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

4.3. Statistical data analyses

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

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

Each dietary source (i.e. C$_4$, C$_3$, legumes, camelids (Group 1 and Group 2), guinea pigs and deer) was condensed into an average δ^{13}C and δ^{15}N value (± 1σ) and used as the source dietary input for the model (Table 2).

Table 2

Average δ13C and δ15N values for the different dietary source used in the SIAR mixing models in this study (data compiled from DeNiro and Hastorf, 1985; Finucane et al., 2006; Turner et al., 2010).

Source	Mean δ^{13}C (‰)	1σ	Mean δ^{15}N (‰)	1σ
C$_4$	−11.4	0.5	5.3	2. 6
Legumes	−25.3	1.2	2.4	1.8
C$_3$	−26.0	0.9	4.6	2.1
Camelids-Group 1	−18.2	1.6	6.4	1.7
Camelids-Group 2	−10.1	1.3	6.5	1.4
Guinea pig	−10.9	3.7	8.4	0.8
White-tailed Deer	−18.9	0.3	8.0	1.4

5. Results

5.1. Radiocarbon dates

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

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

5.2. Stable isotope data

Atomic C/N ratios calculated for all samples range between 2.9 and 3.6, suggesting bone and tooth collagen was well preserved (Ambrose and Norr, 1993; DeNiro and Hastorf, 1985). The δ^{13}C values of human collagen from La Galgada range from –22.2‰ to −12.9‰ with an average value of −18.2‰, whereas the δ^{15}N values range from 5.8‰ to 11.3‰ with an average value of 8.1‰ (Table 4, Fig. 4).

Using a one-way ANOVA test, we found significant differences (F (2,29) = 22.53, p = 0.0001)) in δ^{13}C values, when comparing individuals dating to all three time periods (i.e. the Late Preceramic (n = 20), Initial (n = 6) and Late Intermediate (n = 6) Periods). A Tukey-Kramer post-hoc test was used due to unequal sample sizes, to evaluate which groups significantly differed from one another other. The benefit of this post-hoc test is in its ability to determine significance between two groups while taking into consideration all data. This is in contrast to a traditional *t*-test which requires the systematic comparison of two groups while ignoring the group not under investigation. If the calculated Q value ≥ Q$_{crit}$ (based on Q-table) then a significant difference is detected. Alternatively, if our calculated Q value is < Q$_{crit}$ then no significant difference was detected between groups. This test demonstrated that while the δ^{13}C values of Late Preceramic and Initial Period individuals did not differ significantly at α = 0.05 ((Q$_{crit}$) = 3.493 Q$_{calculated}$ = 1.07), there is a significant difference between the δ^{13}C values of both the Late Preceramic and Initial Periods when compared to the Late Intermediate Period values (Late Preceramic to LIP: ((Q$_{crit}$) = 3.493 < Q = 8.93); Initial to LIP: ((Q$_{crit}$) = 3.493 < Q$_{calculated}$ = 8.06).

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

Table 3
All Radiocarbon Dates for La Galgada.

Lab. number	Material	Tomb Context	C^{14} (BP)	SHCal13 (68.2%)	SHCal13 (95.4%)
MAMS-27353	Human bone	E-11:J-7; Gallery	648 ± 15	CE 1320(55.9%)1350 1386(12.3%)1394	CE 1314(71.8%)1359 1380(23.6%)1400
MAMS-27352	Human bone	E-11:J-7; Gallery	629 ± 20	CE 1324(44.4%)1345 1389(23.8%)1400	CE 1316(58.9%)1355 1381(36.5%)1409
UCIAMS-185732	Human bone	E-11:J-7; Gallery	655 ± 20	CE 1319(57.1%)1351 1385(11.1%)1391	CE 1301(71.8%)1365 1375(23.6%)1400
UCIAMS-185735	Human bone	C-10:E-10	3125 ± 15	1402(22.5%)1374 BCE 1356(45.7%)1301	1416–1271 BCE
UCIAMS-185734	Human bone	G-12:I-2; Chamber	3130 ± 15	1407(26.1%)1375 BCE 1351(42.1%)1303	1422–1277 BCE
TX-4446	Burnt wood	G-12:H-4, Floor 8	3130 ± 80	1436–1230 BCE	1530–1110 BCE
TX-5606	Cloth	H-11:G-10	3320 ± 270	1917–1224 BCE	2292-1901BC
TX-2464	Wood	Sector C shaft	3440 ± 80	1873(6.9%)1844 BCE 1814(2.9%)1801 1778(57.3%)1611 1571(1.0%)1566	1906–1503 BCE
TX-3663	Burnt wood	G-11:G-8 Floor 9	3540 ± 50	1889–1749 BCE	1962–1683 BCE
UGa-4583	Burnt wood	H-11:EF-10, Floor 30	3590 ± 75	2009(1.5%)2003 BCE 1977(66.7%)1769	2132(4.0%)2084 BCE 2057(91.4%)1688
TX-4448	Charcoal	H-11:FG10, Floor 15	3650 ± 60	2115(4.2%)2100 BCE 2038(64.0%)1886	2141-1771BC
TX-3166	Burnt wood	C-11: J-6, Floors 3,5,7	3660 ± 80	2133(12.8%)2081 BC 2061(55.4%)1883	2204–1748 BCE
UCIAMS-185290	Human bone	C-12:D-1; Gallery	3665 ± 15	2024–1947 BCE	2116(3.0%)2099 BCE 2038(92.4%)1901
TX-4447	Burnt wood	H-11:EF-10, Floor 30	3670 ± 70	2131(13.0%)2086 BCE 2051(55.2%)1893	2201(88.3%)1863 BCE 1851(7.1%)1772
TX-2463	Burnt wood	Sector D gallery	3740 ± 90	2266(0.9%)2261BC 2206(67.3%)1947	2454(1.3%)2419 BCE 2407(1.3%)2377 2351(91.8%)1877 1840(0.6%)1825 1794(0.4%)1783
UCIAMS–185730	Human bone	C-11:F-5; Chamber	3770 ± 15	2196(19.7%)2171 BCE 2147(14.6%)2128 2089(33.9%)2046	2201(52.4%)2110 BCE 2105(43.0%)2036
MAMS-27354	Human bone	C-10:I1-0; Gallery	3780 ± 15	2199(31.8%)2160 BCE 2154(16.8%)2131 2085(19.7%)2055	2269(1.2%)2260 BCE 2206(94.2%)2036
TX-4449	Charcoal	E-12: I2, Floor 6	3790 ± 70	2334(1.3%)2325 2301(64.7%)2017 1995(2.2%)1981	2466–1911
UCIAMS–185731	Human bone	D-11:C-3; Chamber	3800 ± 20	2271(15.3%)2259 BCE 2207(60.8%)2135 2070(2.1%)2065	2286(11.7%)2247 BCE 2235(68.7%)2121 2094(14.9%)2042
TX-3167	Burnt wood	D-11: C-3, Floor 25	3820 ± 60	2296(59.4%)2130 2086(8.8%)2050	2456(3.6%)2418 2408(3.7%)2374 2368(68.2%)2030
UCIAMS-185733	Human bone	F-12:B-2; Chamber	3820 ± 20	2278(18.2%)2251 BCE 2229(4.5%)2221 2211(15.0%)2190 2181(30.5%)2142	2295(91.8%)2131 BCE 2085(3.6%)2057
TX-4450	Charcoal	F-12: B-2, firepit	3820 ± 100	2389(0.6%)2386 2346(67.6%)2036	2476–1926
TX-3664	Burnt wood	I-11: D-5, related to floor 40	4110 ± 50	2840(8.5%)2814 2677(44.4%)2559 2536(15.3%)2491	2865(14.5%)2804 2762(80.9%)2472

To assess the proportions of potential food resources (i.e. C$_4$, C$_3$, leguminous plants, camelids and guinea pigs) in each individuals diet at La Galgada we ran a SIAR Mixing Model. Each individuals δ^{13}C and δ^{15}N value was input into the model and sorted by the tomb context in which the remains were found. The SIAR mixing model averages these input values for each tomb context and estimates the probability of the percentage (i.e. 25, 75, 95%) of diet for each dietary source. Each graph in Fig. 5 represents a dietary source. These graphs can be viewed individually to compare a specific dietary source between multiple tomb contexts or as a whole to estimate the proportion of each dietary source per tomb context in relation to an estimated "complete" diet.

5.3. A late Preceramic period and initial period model results

The results of these simulations suggest that the majority of individuals from tombs dating to the Late Preceramic and Initial Periods have diets consisting of primarily C$_3$ plants and low levels of terrestrial meat consumption (Fig. 5). C$_3$ plants make up to 40% of modeled diet for individuals during this time period (Fig. 5A). Leguminous and C$_4$ plant consumption are more varied throughout these two cultural time periods (Fig. 5B, C). The majority of tombs have an average leguminous plant consumption of up to 30% of the modeled diet. When analyzing the 25 and 75% credibility intervals, tomb C-11:F-5 has a lower percentage of leguminous plant consumption of up to only 15% (Fig. 5C).

The mixing model results for the consumption of C$_4$ plants (i.e. hypothesized maize consumption) are more varied across both time
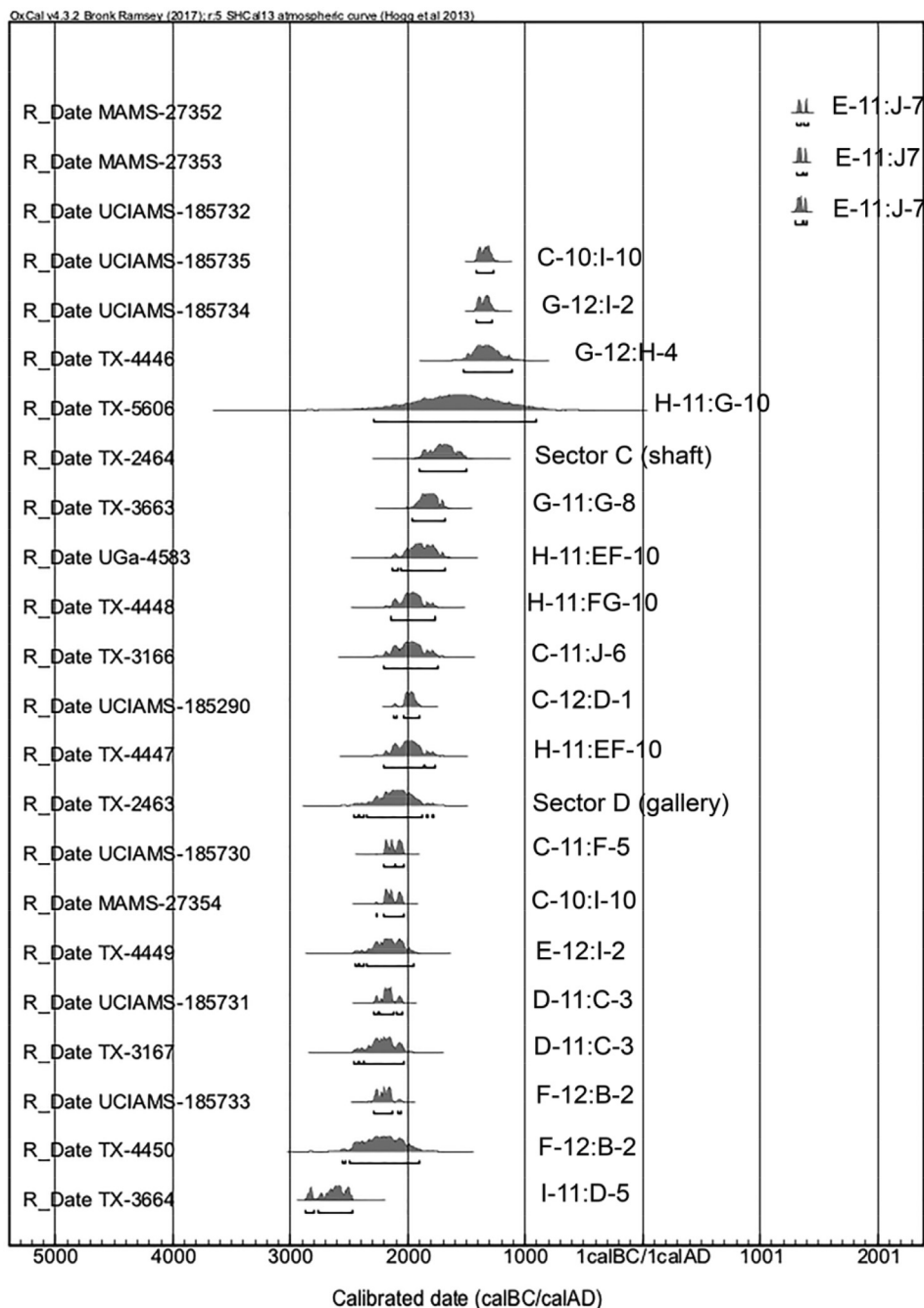
Fig. 3. Calibrated radiocarbon dates from La Galgada. Radiocarbon dates were calibrated with OxCal 4.3.2 with the SHCal13 calibration curve (Hogg et al., 2013).

periods (Fig. 5B). During the Late Preceramic period, tomb F12-B2 averages 15% consumption, although there is only one individual tested from this tomb. Tombs D-11:C-3, C-10:I-10, C-11:F-5, and C-12:D-1 are consuming essentially no C_4 plants when comparing the 25% credibility intervals.

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

5.4. b late Intermediate period model results

Diet during the LIP changes drastically, this result is not surprising however, due to the significant time gap between site usage and the potential different populations present in the valley during this time period. C_3 plant consumption drops significantly to as low as 15% of the modeled diet (Fig. 5A) while C_4 plant consumption increased to 30% (Fig. 5B). There are virtually no leguminous plants consumed during this time period (Fig. 5C) as well as low levels of wild camelids (Fig. 5D). Foddered camelids make up to 35% of the estimated diet, while all other meat sources (i.e. guinea pigs and deer) remain important dietary sources as well (Fig. 5F, G).

Table 4

Archaeological contexts and stable isotope values from human samples from La Galgada.

No.	Sample	Tomb	Sex	*Age*	Bone/Tooth	δ^{13}C (‰) collagen	δ^{15}N (‰) collagen	C/N collagen
1	LGA 18 MAL 21	Tomb F-12:B-2	?	Adult	M²	−19.1	8.2	2.9
2	LGA 26 MAL 31	Tomb D-11:C-3	?	45–50	Metatarsal	−18.2	11	3.0
3	LGA 40 MAL 45	Tomb D-11:C-3	?	Adult	M₂	−19.3	7.4	2.9
4	LGA 41 MAL 46	Tomb D-11:C-3	?	Adult	M₃	−19.9	6.3	2.9
5	LGA 42 MAL 47	Tomb D-11:C-3	?	Adult	M₃	−19.1	7.5	2.9
6	LGA 3 MAL 05	Tomb C-10:I-10	?	Adult	M₃	−19.4	6.7	3.0
7	LGA 38 MAL 43	Tomb C-10:I-10	?	Adult	Metacarpal	−19.2	6.9	2.9
8	LGA 43 MAL 48	Tomb C-10:I-10	?	Adult	Metatarsal	#DIV/0!	5.8	3.0
9	LGA 4 MAL 06	Tomb C-11:F-5	M	Adult	M₃	−19.3	6.8	3.4
10	LGA 7 MAL 09	Tomb C-11:F-5	?	Adult	Metatarsal 1	−19.3	6.7	3.0
11	LGA 8 MAL 10	Tomb C-11:F-5	?	Adult	Metatarsal 1	−19.1	7	2.9
12	LGA 22 MAL 26	Tomb C-11:F-5	?	Adult	M³	−19	8.1	3.0
13	LGA 23 MAL 27	Tomb C-11:F-5	?	Adult	Metacarpal	−18.8	6.8	3.0
14	LGA 24 MAL 28	Tomb C-11:F-5	?	Adult	M²	−18.8	9	3.4
15	LGA 13 MAL 16	Tomb C-12:D-1	F	Adult	M₃	−13.4	9.1	2.9
16	LGA 14 MAL 17	Tomb C-12:D-1	?	Adult	M₃	−18.4	11.3	2.9
17	LGA 15 MAL 18	Tomb C-12:D-1	?	Adult	M₃	−18.5	11.3	2.9
18	LGA 16 MAL 19	Tomb C-12:D-1	?	Adult	M₃	−18.7	10.7	2.9
19	LGA 17 MAL 20	Tomb C-12:D-1	?	Adult	Metatarsal	−19.1	8	3.1
20	LGA 20 MAL 23	Tomb C-12:D-1	?	Adult	Cranial Frag.	−22.2	6.8	2.9
21	LGA 2 MAL 04	Tomb G:12:I-2	?	Adult	Metatarsal 1	−19.5	7.1	3.0
22	LGA 11 MAL 13	Tomb C-11:E-8	?	Adult	Metatarsal 1	−20.7	6.7	3.5
23	LGA 44 MAL 49	Tomb C-11:E-8	?	Adult	M₂	−18.3	10.5	2.9
24	LGA 12 MAL 14	Tomb C-10:E-10	F	Adult	M₂	−19.4	6.4	2.9
25	LGA 12 MAL 15	Tomb C-10:E-10	F	Adult	Metatarsal	−19.3	5.9	2.9
26	LGA 21 MAL 24	Tomb C-10:E-10	F	40–70	M²	−19.5	6.8	2.9
27	LGA 29 MAL 34	Tomb E-11:J-7	?	Juvenile	M₂	−14.6	8.9	2.9
28	LGA 30 MAL 35	Tomb E-11:J-7	?	Young Adult	M₂	−17.4	11.3	3.5
29	LGA 31 MAL 36	Tomb E-11:J-7	?	30–45	M₂	−12.9	10	2.9
30	LGA 33 MAL 38	Tomb E-11:J-7	?	Adult	Metatarsal	−15.4	10.3	3.0
31	LGA 34 MAL 39	Tomb E-11:J-7	?	Adult	Metatarsal	−14.3	10.6	3.1
32	LGA 35 MAL 40	Tomb E-11:J-7	?	Adult	Metatarsal 1	−13.5	10.1	2.9
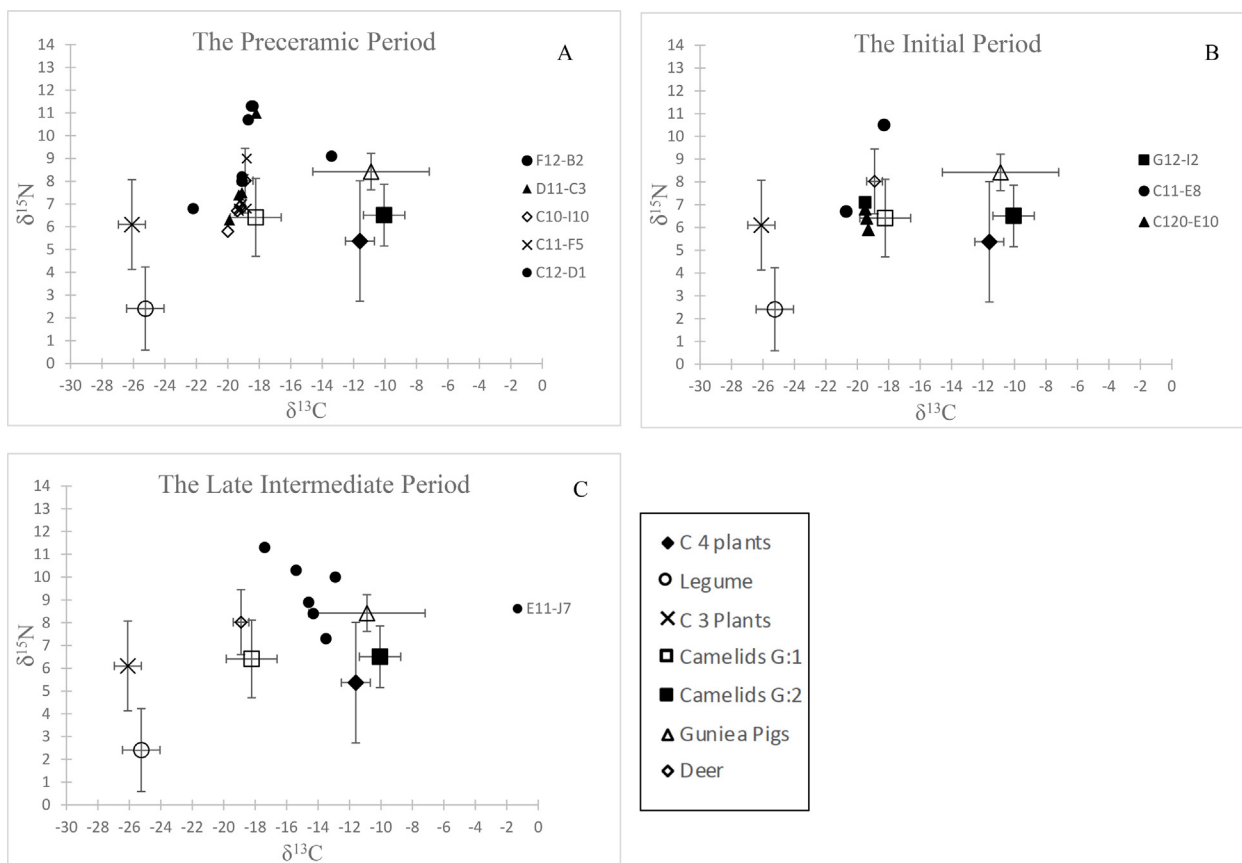
Fig. 4. Bulk stable isotope data from archaeological human remains at La Galgada, grouped by tomb association (see Table 4) as well as potential food resources in the region.
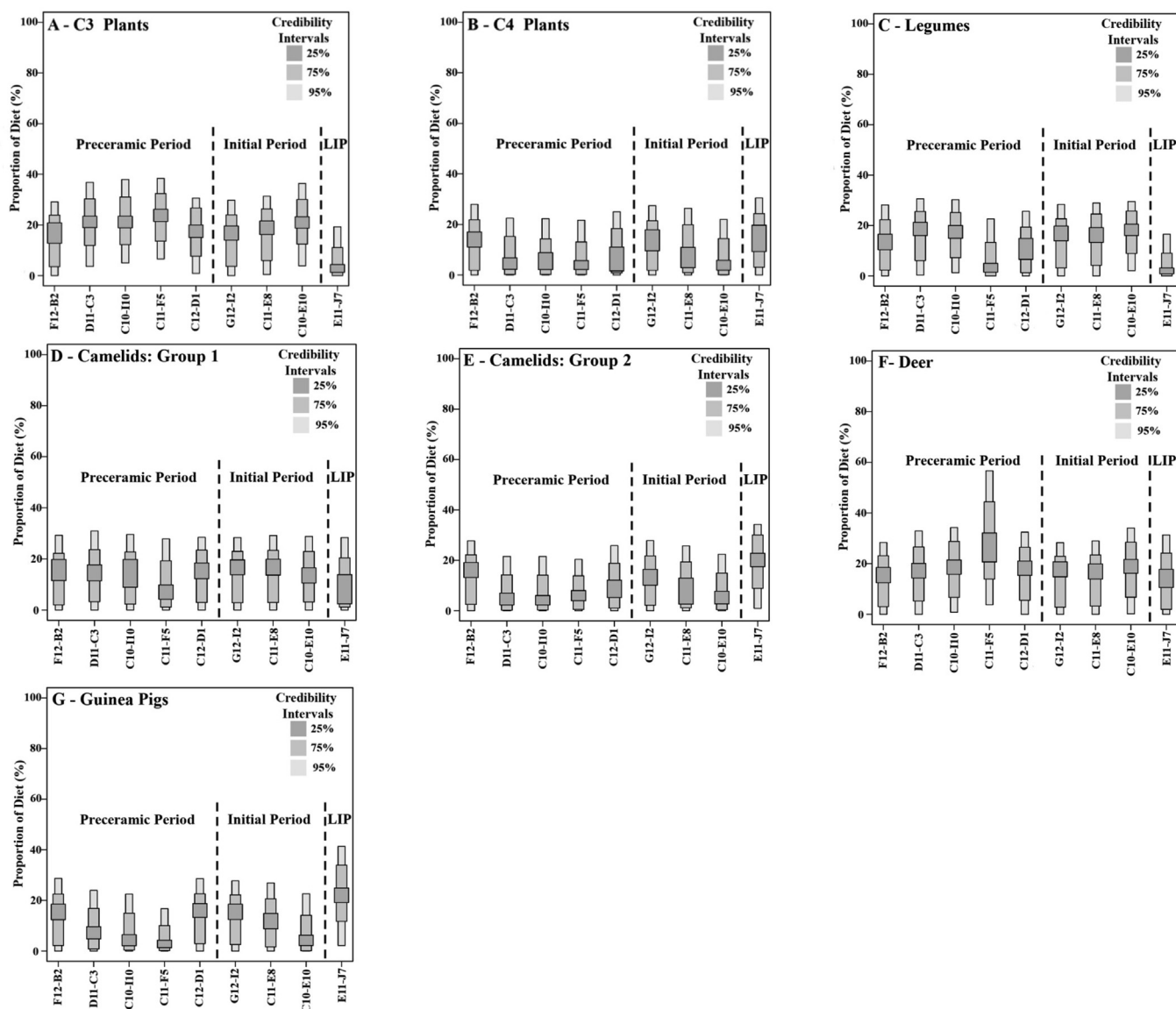
Fig. 5. Results of the SIAR Mixing Models of human diets at La Galgada shown for the five main potential food resources. 25, 75 and 95% credibility intervals are plotted for each tomb context (see Table 4 for detailed description of each tomb context.

6. Discussion

6.1. The use of mixing models to reconstruct diet

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

First, model accuracy is limited by the quality and quantity of available food source data. Second, the model lacks the ability to accurately distinguish between source groups that overlap in their isotope values. This can present a challenge when inputting data for groups who isotopic signatures are quite similar. For example, in this study all guinea pigs were grouped together as a potential food source despite their large variation in isotope values and there is slight isotopic overlap between this group, C_4 plants and Camelids: Group 2. Third, the more potential food sources input for a model the lower the resolution becomes. This model has a limit of 30 groups (i.e. tomb contexts – n = 9) and between 3 and 7 observations (i.e. dietary source groups; n = 7). Despite these limitations, mixing models allow us to estimate, quantify and discuss the relative contribution of certain food categories to past human diets, which is of considerable value to the archeological interpretation of past lifeways.

6.2. Human diet at La Galgada during the late Preceramic and initial periods

At La Galgada no faunal remains were found. This surprising lack of faunal remains and the relative abundance of botanical remains found and analyzed (Smith, 1988) have been used to suggest a primarily plant-based diet focusing on available C_3 and Leguminious plants

(Grieder et al.,1988), although the excavations primarily focused on the monumental architectural complex. The majority of food remains were found both within the complex and within fire-pits found within burial chambers.

Interestingly, given the potential for missed remnants of food remains, our isotope data suggests that the majority of individuals found dating to the occupation of this site exhibit a dietary pattern consistent with the interpretations made by Grieder and colleagues (1988). Diet consisted of a primarily C_3 plant-based diet with only limited amounts of terrestrial protein (Figs. 3 and 5).

There are, however, several interesting deviations from this overall pattern. First, our isotope data indicates that three adult individuals from tomb C-12:D-1 (LGA 14, 15, 16 – sex unknown) that dates to the Late Preceramic Period, show elevated $\delta^{15}N$ indicating a potentially higher reliance on terrestrial protein when compared with other contemporary burials (Fig. 4A). Our data suggests that there is little change in the pattern of meat consumption between the Late Preceramic and the Initial Periods; though this is not surprising since in highland Ancash domesticated camelids did not displace hunted animals until around 800 cal BCE (Miller and Burger, 1995; Miller, 1984; Rosenfeld and Sayre, 2016; Sawyer, 1985; Uzawa, 2010).

Second, one adult female (LGA 13) from burial C:12-D:1 exhibits a higher bulk $\delta^{13}C$ value (-13.4‰), falling within the expected range of C_4 plants, possibly indicating high maize consumption (Fig. 4A). While this individual is unique compared with other contemporary individuals, the potential consumption of maize by this individual, fits with the idea that while present, maize did not become a dietary staple until much later. It is also possible that this individual was not local to La Galgada but migrated to the site, however this interpretation has not yet been substantiated.

6.3. Human diet at La Galgada during the late intermediate period

Gallery tomb E-11:J-7 (n = 6), which based on our radiocarbon dates, dates to the Late Intermediate Period, exhibits a considerable change in subsistence. Individuals buried in this tomb show an increased proportion of foddered camelid (camelids - group 2) and guinea pig consumption and a lower proportion of C_3 plants and leguminous plants in the modeled diet (Fig. 5). C_4 plant consumption seems to have remained low at ~ 30%, however, this could alternatively be explained by the increase in the proportion of foddered camelids and guinea pigs who also fed on C_4 plants (see further discussion below).

6.4. Maize consumption during the late Preceramic, initial and late intermediate periods

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

The results of this study confirm that during the Late Preceramic and Initial Periods, individual diet remained reliant on local productivity with a mixed subsistence economy characterized by a heavy reliance on plants. Except for one individual (LGA13) there are no observed changes of $\delta^{13}C$ values coincident with the transition into the Initial Period that would suggest a dietary shift to a largely maize based diet (Fig. 5B). Thus, it is probable that consumption of maize was not a

common practice yet, even if maize itself was known to the region.

Subsistence practices in the Tablachaca Valley between the abandonment of La Galgada and the re-use of the site during the LIP changed significantly. Subsistence practices during the LIP include an increase in intensive agriculture as well as animal husbandry. $\delta^{13}C$ and $\delta^{15}N$ isotope values (Fig. 4) of all individuals dating to the LIP suggest consumption of a primarily C_4 plant-based diet (i.e. presumably maize). In the Andes, this observation has commonly been used to indicate human primary consumption of maize. However, the use of dietary mixing models may challenge this assumption by taking the analysis of carbon and nitrogen isotope data an important step further by allowing us to distinguish between different proportions of food categories.

When plotted against each other, the bulk $\delta^{13}C$ and $\delta^{15}N$ isotope data clearly shows a C_4 signal in the diet of all LIP individuals (Fig. 4C). But, does this signal indicate primary consumption of maize or is this signal an indicator of the consumption animals that were feed through the cultivation of mainly maize?

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

7. Conclusions

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

CRediT authorship contribution statement

Eden Washburn: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing - review & editing, Supervision, Funding acquisition. **Jason Nesbitt:** Writing - original draft, Writing - review & editing, Visualization. **Richard Burger:** Writing - review & editing, Supervision. **Elsa Tomasto-Cagigao:** Resources. **Vicky M. Oelze:** Methodology, Writing - review & editing, Supervision. **Lars Fehren-Schmitz:** Conceptualization, Methodology, Data curation, Writing - review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to

Appendix

A1: All dietary source data used in mixing model simulations. Source data was limited to ecological zones with similar conditions to La Galgada and was compiled from DeNiro and Hastorf (1985), Finucane et al (2006) and Turner et al (2010). Dietary plant data compiled from DeNiro and Hastorf (1985) was limited to modern uncarbonized plants.

Family	Genus & Species	Portion	Common Name	Photo. Path	Original Cat. No.	δ^{13}C	δ^{15}N	Source
Poaceae	*Zea mays*	Seed	Maize	C4	086	−10.8	7.9	DeNiro and Hastorf 1985
	Zea mays	Seed	Maize	C4	086d	−11.6	8.1	DeNiro and Hastorf 1985
	Zea mays	Seed	Maize	C4	086 g	−14.3	6.6	DeNiro and Hastorf 1985
	Zea mays	Seed	Maize	C4	086dg	−12.0	8.5	DeNiro and Hastorf 1985
	Zea mays	Seed	Maize	C4	086dgh	−11.8	8.6	DeNiro and Hastorf 1985
	Zea mays	Seed	Maize	C4	086dghi	−11.6	7.4	DeNiro and Hastorf 1985
	Zea mays	Cob	Maize	C4	126–1	−11.4	3.6	DeNiro and Hastorf 1985
	Zea mays	Cob	Maize	C4	126-1b	−11.6	2.9	DeNiro and Hastorf 1985
	Zea mays	Cob	Maize	C4	126-1c	−12.2	2.1	DeNiro and Hastorf 1985
	Zea mays	Cob	Maize	C4	126-1d	−10.3	3.0	DeNiro and Hastorf 1985
	Zea mays	Cob	Maize	C4	126-1bd	−11.4	2.5	DeNiro and Hastorf 1985
	Zea mays	Cob	Maize	C4	126–1 cd	−11.3	2.3	DeNiro and Hastorf 1985
	Zea mays	Cob	Maize	C4	126-1e	−10.9	4,7	DeNiro and Hastorf 1985
	Zea mays	Cob	Maize	C4	126–2	−11.2	3.9	DeNiro and Hastorf 1985
Fabaceae	*Archchis hypogaea*	Seed	Peanut	legume	285–1	−26.7	0.6	DeNiro and Hastorf 1985
	Archchis hypogaea	Husk	Peanut	legume	285–2	−25.8	1.2	DeNiro and Hastorf 1985
	Lupinus mutabilu	Seed	Tarwi	legume	061	–23.2	0.4	DeNiro and Hastorf 1985
	Lupinus mutabilu	Seed	Tarwi	legume	061d	−25.9	2.0	DeNiro and Hastorf 1985
	Pachyrhizus erosus	Root	Jícama	legume	125	−24.8	2.4	DeNiro and Hastorf 1985
	Pachyrhizus erosus	Root	Jícama	legume	125b	−25.9	2.5	DeNiro and Hastorf 1985
	Pachyrhizus erosus	Root	Jícama	legume	125c	−24.8	3.2	DeNiro and Hastorf 1985
	Pachyrhizus erosus	Root	Jícama	legume	125d	−25.7	2.3	DeNiro and Hastorf 1985
	Pachyrhizus erosus	Root	Jícama	legume	125bd	−25.8	2.9	DeNiro and Hastorf 1985
	Pachyrhizus erosus	Root	Jícama	legume	125 cd	−24.6	3.0	DeNiro and Hastorf 1985
	Pachyrhizus erosus	Root	Jícama	legume	125e	−24.8	3.6	DeNiro and Hastorf 1985
	Phaseolus lunatus	Seed	Lima Bean	legume	076	−24.9	− 0.2	DeNiro and Hastorf 1985
	Phaseolus lunatus	Seed	Lima Bean	legume	076d	−21.7	1.3	DeNiro and Hastorf 1985
	Phaseoleum lunatus	Seed	Lima Bean	Legume	N.A.	–25.0	0.9	Turner et al 2010
	Phaseoleum lunatus	Seed	Lima Bean	Legume	N.A.	–25.0	0.2	Turner et al 2010
	Phaseoleum lunatus	Seed	Lima Bean	Legume	N.A.	–26.0	0.1	Turner et al 2010
	Phaseoleum lunatus	Seed	Lima Bean	Legume	N.A.	–24.1	0.9	Turner et al 2010
	Phaseoleum lunatus	Seed	Lima Bean	Legume	N.A.	–24.3	1.4	Turner et al 2010
	Phaseoleum lunatus	Seed	Lima Bean	Legume	N.A.	–24.2	0.9	Turner et al 2010
	Phaseoleum lunatus	Seed	Lima Bean	Legume	N.A.	–24.7	0.8	Turner et al 2010
	Phaseoleum lunatus	Seed	Lima Bean	Legume	N.A.	–24.8	0.8	Turner et al 2010
	Phaseoleum lunatus	Seed	Lima Bean	Legume	N.A.	–24.8	0.3	Turner et al 2010
	Phaseoleum lunatus	Seed	Lima Bean	Legume	N.A.	–24.8	0.5	Turner et al 2010
	Phaseolus Vulgaris	Pod	Common Bean	legume	128	−25.9	4.2	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	128b	−26.4	3.5	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	128c	−26.9	6.0	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	128d	−26.4	5.9	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	128bd	−26.5	3.9	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	128 cd	−25.2	4.3	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	128e	−26.0	4.5	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Pod	Common Bean	legume	077	−25.4	1.8	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	077d	−25.8	2.8	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	077ghi	−26.9	0.7	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	077dghi	−26.1	2.2	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Pod	Common Bean	legume	232	−24.5	4.0	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Pod	Common Bean	legume	232d	−26.2	4.5	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Pod	Common Bean	legume	232dj	−25.1	3.6	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	226	−25.3	5.7	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	226d	−25.7	**4.4**	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	226j	−26.5	5.9	DeNiro and Hastorf 1985
	Phaseolus Vulgaris	Seed	Common Bean	legume	226dj	−25.9	4.4	DeNiro and Hastorf 1985
	Pisum sativum	Pod	Common Pea	legume	235	−21.5	0.3	DeNiro and Hastorf 1985
	Pisum sativum	Pod	Common Pea	legume	235d	–23.6	0.6	DeNiro and Hastorf 1985

Solanaceae	Solanum stenotonium	Tuber			C3	071	−26.5	5.4	DeNiro and Hastorf 1985
	Solanum stenotonium	Tuber			C3	071d	−26.3	6.0	DeNiro and Hastorf 1985
	Solanum stenotonium	Tuber			C3	071dg	−26.2	7.8	DeNiro and Hastorf 1985
	Solanum tuberosum	Tuber	Potato		C3	229	−26.6	3.4	DeNiro and Hastorf 1985
	Solanum tuberosum	Tuber	Potato		C3	229d	−26.8	4.2	DeNiro and Hastorf 1985
	Solanum tuberosum	Tuber	Potato		C3	229j	−28.0	5.8	DeNiro and Hastorf 1985
	Solanum tuberosum	Tuber	Potato		C3	229dj	−27.1	2.6	DeNiro and Hastorf 1985
	Capsicum annum	Seed	Sweet and Chili Peppers		C3	238	−26.4	3.4	DeNiro and Hastorf 1985
	Capsicum annum	Seed	Sweet and Chili Peppers		C3	238d	−26.9	2.7	DeNiro and Hastorf 1985
	Capsicum annum	Seed	Sweet and Chili Peppers		C3	238j	−26.5	5.6	DeNiro and Hastorf 1985
	Capsicum annum	Seed	Sweet and Chili Peppers		C3	238dj	−28.2	2.7	DeNiro and Hastorf 1985
	Capsicum annum	Seed	Sweet and Chili Peppers		C3	129	−28.4	3.8	DeNiro and Hastorf 1985
	Capsicum annum	Seed	Sweet and Chili Peppers		C3	129b	−29.2	5.5	DeNiro and Hastorf 1985
	Capsicum annum	Seed	Sweet and Chili Peppers		C3	129c	−26.7	3.6	DeNiro and Hastorf 1985
	Capsicum annum	Seed	Sweet and Chili Peppers		C3	129d	−28.2	0.5	DeNiro and Hastorf 1985
	Capsicum annum	Seed	Sweet and Chili Peppers		C3	129bd	−30.0	3.3	DeNiro and Hastorf 1985
	Capsicum annum	Seed	Sweet and Chili Peppers		C3	129 cd	−27.8	2.2	DeNiro and Hastorf 1985
	Capsicum annum	Seed	Sweet and Chili Peppers		C3	129e	−27.6	0.6	DeNiro and Hastorf 1985
Tropoelacaea	Tropaeolum tuberosum	Tuber	Mashua		C3	072	−25.1	4.2	DeNiro and Hastorf 1985
	Tropaeolum tuberosum	Tuber	Mashua		C3	072d	−25.0	5.0	DeNiro and Hastorf 1985
	Tropaeolum tuberosum	Tuber	Mashua		C3	072 g	−25.6	5.8	DeNiro and Hastorf 1985
	Tropaeolum tuberosum	Tuber	Mashua		C3	072dg	−25.0	7.5	DeNiro and Hastorf 1985
Basellaceae	Ullucus tuberosus	Tuber	Ulluco		C3	067	–23.0	6.4	DeNiro and Hastorf 1985
	Ullucus tuberosus	Tuber	Ulluco		C3	067d	–22.9	6.8	DeNiro and Hastorf 1985
Brassicaceae	Lepidium meyenii	Root	Maca		C3	082	−25.1	2.4	DeNiro and Hastorf 1985
	Lepidium meyenii	Root	Maca		C3	082d	−26.7	3.0	DeNiro and Hastorf 1985
Chenopodiaceae	Chenopodium quinoa	Seed	Quinoa		C3	074	−25.0	4.0	DeNiro and Hastorf 1985
	Chenopodium quinoa	Seed	Quinoa		C3	074d	−25.4	6.7	DeNiro and Hastorf 1985
	Chenopodium quinoa	Seed	Quinoa		C3	N.A.	–25.2	7.7	Turner et al 2010
	Chenopodium quinoa	Seed	Quinoa		C3	N.A.	−26.0	8.7	Turner et al 2010
	Chenopodium quinoa	Seed	Quinoa		C3	N.A.	−25.1	8	Turner et al 2010
	Chenopodium quinoa	Seed	Quinoa		C3	N.A.	−25.9	8.8	Turner et al 2010
	Chenopodium quinoa	Seed	Quinoa		C3	N.A.	−25.2	9	Turner et al 2010
Cucurbitaceae	Cucurbita maxima	Fruit	Squash		C3	127	−24.8	3.7	DeNiro and Hastorf 1985
	Cucurbita maxima	Fruit	Squash		C3	127b	−25.0	2.5	DeNiro and Hastorf 1985
	Cucurbita maxima	Fruit	Squash		C3	127c	−24.5	3.3	DeNiro and Hastorf 1985
	Cucurbita maxima	Fruit	Squash		C3	127d	−24.6	3.7	DeNiro and Hastorf 1985
	Cucurbita maxima	Fruit	Squash		C3	127bd	−25.0	3.3	DeNiro and Hastorf 1985
	Cucurbita maxima	Fruit	Squash		C3	127 cd	–23.8	4.0	DeNiro and Hastorf 1985
	Cucurbita maxima	Fruit	Squash		C3	127e	−24.2	5.0	DeNiro and Hastorf 1985
	Cucurbita pepo	Seed	Pumpkin		C3	241	−25.5	5.7	DeNiro and Hastorf 1985
	Cucurbita pepo	Seed	Pumpkin		C3	241d	−25.8	5.2	DeNiro and Hastorf 1985
	Cucurbita pepo	Seed	Pumpkin		C3	241j	−27.3	6.8	DeNiro and Hastorf 1985
	Cucurbita pepo	Seed	Pumpkin		C3	241dj	−26.7	6.7	DeNiro and Hastorf 1985
	Lagenaria siceraria	Fruit	Calabash		C3	079	−25.1	5.2	DeNiro and Hastorf 1985
	Lagenaria siceraria	Fruit	Calabash		C3	079d	−25.1	5.4	DeNiro and Hastorf 1985
	Lagenaria siceraria	Fruit	Calabash		C3	079 g	−25.3	2.7	DeNiro and Hastorf 1985
	Lagenaria siceraria	Fruit	Calabash		C3	079dg	−25.0	4.9	DeNiro and Hastorf 1985
Oxalidaceae	Oxalis tuberosa	Pod	Oca		C3	064	−24.8	3.2	DeNiro and Hastorf 1985
	Oxalis tuberosa	Pod	Oca		C3	064d	−25.8	4.2	DeNiro and Hastorf 1985
	Oxalis tuberosa	Pod	Oca		C3	064 g	−26.1	2.7	DeNiro and Hastorf 1985
	Oxalis tuberosa	Pod	Oca		C3	064gh	−26.6	2.4	DeNiro and Hastorf 1985
	Oxalis tuberosa	Pod	Oca		C3	064ghi	−26.8	2.2	DeNiro and Hastorf, 1985
	Camelid	Bone					−18.9	5.9	Finucane et al 2006
	Camelid	Bone					−9.7	7.5	Finucane et al 2006
	Camelid	Bone					−12.1	6.3	Finucane et al 2006
	Camelid	Bone					−8.5	4.9	Finucane et al 2006
	Camelid	Bone					−9	6.3	Finucane et al 2006
	Camelid	Bone					−11.2	9.6	Finucane et al 2006
	Camelid	Bone					−11.2	6.4	Finucane et al 2006
	Camelid	Bone					−11.9	4.6	Finucane et al 2006
	Camelid	Bone					−16.8	5	Finucane et al 2006
	Camelid	Bone					−9.8	6.6	Finucane et al 2006
	Vicugna pacas	Bone					−19.2	8.6	Finucane et al 2006
	Camelid	Bone					−9.2	6.4	Finucane et al 2006
	Camelid	Bone					−9.3	7.6	Finucane et al 2006
	Camelid	Bone					−19.5	8	Finucane et al 2006
	Camelid	Bone					−8.2	5.1	Finucane et al 2006
	Camelid	Bone					−18.8	8.9	Finucane et al 2006
	Camelid	Bone					−18.5	5	Finucane et al 2006
	Cavia porcellus	Bone	guinea pig				−11.3	9.3	Finucane et al 2006
	Cavia porcellus	Bone	guinea pig				−7.4	8.9	Finucane et al 2006
	Cavia porcellus	Bone	guinea pig				−9.9	8.4	Finucane et al 2006
	Cavia porcellus	Bone	guinea pig				−12.4	8.3	Finucane et al 2006
	Cavia porcellus	Bone	guinea pig				−18.6	8.2	Finucane et al 2006
	Cavia porcellus	Bone	guinea pig				−16.1	8.7	Finucane et al 2006
	Cavia porcellus	Bone	guinea pig				−11.8	9.1	Finucane et al 2006
	Cavia porcellus	Bone	guinea pig				−7	10.3	Finucane et al 2006
	Cavia porcellus	Bone	guinea pig				−12.6	7.8	Finucane et al 2006
	Cavia porcellus	Bone	guinea pig				−7.6	7.4	Finucane et al 2006

Cavia porcellus	Bone	guinea pig		−14.6	7.9	Finucane et al 2006
Cavia porcellus	Bone	guinea pig		−6.4	7.4	Finucane et al 2006
Cavia porcellus	Bone	guinea pig		−8.2	8.1	Finucane et al 2006
Cavia porcellus	Bone	guinea pig		−8.5	8.1	Finucane et al 2006

A2: δ13C and δ15N isotope values from four deer excavated from the highland archaeological site of Canchas Uckro.

Sample ID	Provenience	Species	Material	$\delta^{13}C$	$\delta^{15}N$	C/N
CUO-NH-1	Unit 7B layer 1	*Odocoileus virginianus*	Dentine	−19.4	8.6	3.3
CUO-NH-3	Unit 7B layer 2	*Odocoileus virginianus*	Bone	−18.7	8.9	3.35
CUO-NH-4	Unit 8D layer 2	*Odocoileus virginianus*	Dentine	−18.8	8.7	3.24
CUO-NH-5	Unit 8C Layer 2	*Odocoileus virginianus*	Dentine	−18.7	5.9	3.19

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