Journal of Archaeological Science: Reports 4 (2015) 371–386

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: http://ees.elsevier.com/jasrep

Diet in Peru's pre-Hispanic central coast

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ARTICLE INFO

Article history:
Received 27 May 2015
Received in revised form 22 September 2015
Accepted 23 September 2015
Available online 23 October 2015

Keywords:
Maize
Seafood
Environment
Stable isotopes
Andes
Pre-Columbian

ABSTRACT

The Tablada de Lurín cemetery (200 BC–AD 200; Lima, Peru) is characterised by two mortuary phases. Based on associated grave finds and the lack of habitation sites near the cemetery, it has been hypothesised that both burial populations came from a certain distance of the site (*ca.* 20 km) and that they relied on land rather than marine resources. We tested these hypotheses, based on material culture, through stable isotope analysis. The aim was to understand the populations' diet and geographic origins. We sampled 47 human individuals and eleven sets of faunal remains from both phases for stable isotope analysis (carbon, nitrogen, sulphur and oxygen) of bone and dental collagen, and apatite. Modern samples of autochthonous food were also tested as a baseline for comparison. The results showed preservation differences between the remains from both phases. Individuals from Phase 1 provided the best isotopic dataset and showed consumption of protein from marine resources and C_4 plants. On the other hand, bioapatite carbon and oxygen stable isotope results from both phases highlighted differences in C_4 plant consumption and individuals of possible non-local origin. The results underline the need to study further the effect of brewed or cooked beverages on bioapatite oxygen levels. Finally, results from Phase 1 fit with the broader dietary pattern evident in other Andean sites, where coastal populations consumed marine protein and C_4 plants, as opposed to highland populations who relied on terrestrial protein sources and C_3 plants.

1. Introduction

Isotopic analyses on Andean archaeological populations have been conducted to understand sociopolitical changes, warfare and violence, the transition to agriculture, diet and intra-populational variations in diet, seasonality of death, as well as human migration and mobility patterns (Burger and Van der Merwe, 1990; Buzon et al., 2011; Conlee et al., 2009; Finucane et al., 2006; Henry, 2008; Kellner and Schoeninger, 2008; Knudson et al., 2007, 2009; Tomczak, 2003; Tykot et al., 2006, 2011; Webb et al., 2013a, 2013b; Williams, 2005; Williams and Katzenberg, 2012). Previous research showed that coastal populations after the development of agriculture tended to rely on C_4 plants (*e.g.*, maize (*Zea mays*)) and seafood (marine proteins) or terrestrial proteins (Tykot et al., 2006; Webb et al., 2013a). Studies in the Nasca region have also revealed the presence of non-locals within the burial populations (Conlee et al., 2009; Webb et al., 2013b).

The site of Tablada de Lurín (Fig. 1), on the Peruvian central coast, with its large funerary occupation of several hundred individuals spanning four centuries (200 BC–AD 200), offers an opportunity to explore further the diet of coastal populations and the local origins of the people buried at the site. Along the Peruvian central coast, the period between the decline of Chavín de Huántar (*ca.* 500 BC; Rodríguez[1] and Haas, 2015) and the

Abbreviations: EIP, Early Intermediate Period; ICRP, International Commission on Radiological Protection; IAEA, International Atomic Energy Agency.

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[1] Spanish and Latin American authors usually have two last names. Please note that for ease of reading, authors are cited in text only with their first last name, but appear in the Literature Cited with both last names in alphabetical order according to the first last name. *E.g.* Rodríguez Kembel is cited as Rodríguez, and listed as Rodríguez Kembel (as this is how the author's name appears in the publication), appearing between the letters Q and S. When authors have a composite last name, this remains unchanged (*e.g.*, Van der Merwe).

http://dx.doi.org/10.1016/j.jasrep.2015.09.016

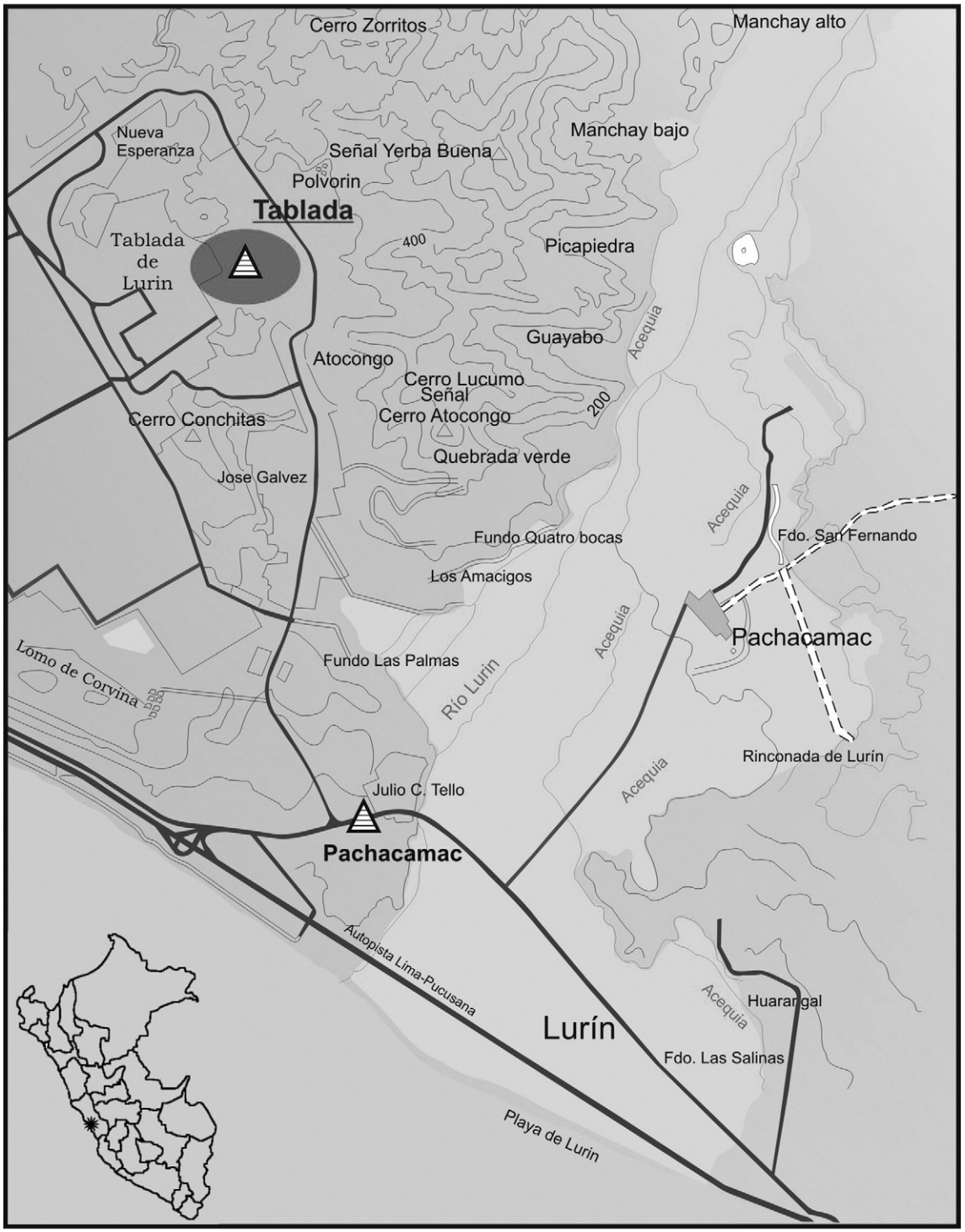

Fig. 1. Location of the archaeological site Tablada de Lurín, Lima, Peru.

appearance of the Lima culture (AD 300–500; Narváez, 2014; Patterson, 1966) sees the establishment of extensive cemeteries (Tablada de Lurín, Ferrocarril, El Panel, and Lomo de Corvina; Maguiña and Paredes, 2009; Pechenkina and Delgado, 2006), but neither large settlement sites nor the construction of large building works, typical of earlier and later periods. It is possible these large cemeteries represent central places of burial, where groups of communities congregated to bury their dead, with a shared set of funerary and religious beliefs.

This study combines isotopic data with material evidence from the burials in order to understand people's dietary habits, livelihoods and local origins. Diet was explored through carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis from human bone and dental samples recovered from Tablada de Lurín. Local origins and migration patterns were inferred through oxygen ($\delta^{18}O$) and sulphur ($\delta^{34}S$) isotopes from the same samples. To the authors' knowledge, this is the first time $\delta^{34}S$ isotope analysis has been conducted on human bone and tooth samples from the central Andes.

1.1. Economic organisation in the pre-Columbian Andes

In 1972, Murra (1972 in Murra, 1975) proposed the concept of 'vertical control' or the 'vertical archipelago' model as an explanation for the economic organisation of indigenous societies at the time of Spanish conquest. Murra studied archival records (1972 in Murra, 1975) and proposed that highland populations had a land holding system of ecological complementarity in which lands were dispersed across several ecological niches and altitudinal gradients. Smaller groups could hold land as far as a five-day walk from the main centre of political and religious power, whereas larger societies could hold land up to 15 days walk from the main centre of power. Furthermore, highland societies could have land holdings in the coast. Due to the altitudinal gradient of the Andes, different crops grow and animal species thrive at different altitudes (Murra, 1972, in Murra, 1975; Pearsall, 2008). The 'vertical archipelago' enables societies to complement their diets and face subsistence hardships when, for example, crops fail in a particular area.

Rostworowski (1977a, 1977b), however, suggested that coastal societies (*señorios*) had no need of the vertical archipelago model to ensure access to different kinds of resources and face potential subsistence difficulties. The sea provided ample source of protein and coastal oases yielded a variety of crops. Through archival analysis of early colonial documents, Rostworowski (1970, 1977a, 1977b) suggested that societies in what is now the Peruvian coast, were arranged into specialised groups similar to guilds (*gremios*), for example, fishermen, merchants, craftsmen, farmers, *inter alia*. These groups would have lived in separate neighbourhoods and would exchange between themselves. The merchants would also trade the goods across regions (*e.g.*, from the central coast to the north coast, including the Ecuadorian and Colombian coasts; or from the coast to the highlands). Rostworowski (1970) pointed out that though commerce was not part of the Inca economic model, from the colonial accounts it appears to have been part of non-Inca societies before the time of contact and before Inca occupation. According to Rostworowski's (1970, 1977a, 1977b) research, coastal societies had no need for Murra's (1972 in Murra, 1975) 'vertical archipelago' model.

Both Murra (1972 in Murra, 1975) and Rostworowski (1970, 1977a, 1977b) coaxed archaeologists to find evidence for either one of these models. Several archaeological and bioarchaeological studies have looked for evidence (Blom et al., 1998; Lockard and Vexler, 2010; Matthews, 1997; Tomczak, 2003) and in some instances have also proposed alternate models (Kolata, 1986, 1991; Matthews, 1997) that do not necessarily rely on ecological complementarity or exchange. Furthermore, Murra's model has also been revisited through further archival records and archaeological data (Van Buren, 1996).

1.2. Tablada de Lurín

Tablada de Lurín is located in the lower Lurín valley at 12°11′ S, 76°55′ W, south of the capital city of Lima (Fig. 1). There is evidence for occupation and mortuary use of the site from the Preceramic (*ca.* 6000 BC) to modern times. Given the location of the site (close to the capital city of Lima), its extent and length of human use and occupation (as detailed below), teams from the Pontificia Universidad Católica del Perú have worked on site since 1958, conducting research and archaeological fieldschools (Balbuena Cotlear, 1996; Cárdenas, 1999; Cárdenas and Vivar, 1990, 1999; Castro de la Mata, 2005; Gerdau, 2007; Gerdau and Makowski, 2011; Jiménez, 2009; Makowski, 2002, 2009a, 2009b; Makowski and Castro de la Mata, 2000; Makowski et al., 2012; Tomasto, 2005). Over the past 60 years of research, 5200 m^2 have been excavated, but this represents only 3% of the estimated extension of the archaeological site.

The most recent excavations were undertaken in the late 20th and early 21st centuries led by one of the authors (KM). Archaeological evidence indicates the Tablada area had several phases of occupation of different nature and duration. The most significant finds are temporary Pre-ceramic (*ca.* 6000–4000 BC; León, 1999; Salcedo, 2012) and Initial periods (*ca.* 1100–800 BC; Jiménez, 2009) campsites, as well as an extensive cemetery. The mortuary site dates to the period between the abandonment of Chavín de Huántar in the Peruvian highlands (*ca.* 500 BC; Rodríguez and Haas, 2015) and the appearance of the Middle Lima style, architecture, and funerary patterns across the Rímac and Lurín valleys, on the Peruvian central coast according to Patterson's chronology (AD 400–600; Narváez, 2014; Patterson, 1966, 2014). However, the exact chronology is still disputed (Marcone, 2010; Segura and Shimada, 2010).

1.2.1. The cemetery

The mortuary site within Tablada had two distinct chronological phases. This is evident in the stratigraphy of the site. Phase 1 was characterised by single pit burials of individuals in a crouched position (Fig. 2), a recurrent position in the pre-Hispanic central Andes. Phase 2 presents a different funerary ritual to Phase 1. During this second phase individuals were deposited in semi-subterranean stone chambers, containing sequential commingled funerary deposits (Fig. 3).

The bone samples from the site sent for radiocarbon dating had low levels of collagen. It has therefore not been possible to obtain reliable ^{14}C dates (Makowski, 2002) for either mortuary phase. Consequently, the mortuary site has been relatively dated through comparisons of ceramic styles. Imitations of the Topará ceramic style indicate that Phase 1 of the mortuary site is contemporaneous with Phases 9 and 10 of the Early Horizon period from the southern Peruvian coast (*ca.* 200 BC to the beginning of the Common Era; Silverman, 2009; Splitstoser et al., 2009). The pottery of Phase 2 can be compared with materials from the Chancay valley and the ravine of Huachipa-Jicamarca in the central Peruvian coast (Pacaybamba: Goldhausen, 2013; Huayco: Palacios, 1988) and dated to the first two phases of the Early Intermediate Period (EIP; from the beginning of the Common Era to AD 200), according to Patterson (1966), Makowski (2002), and Makowski et al. (2012).

Archaeological surveys around the site have not been able to identify any potential settlements dating to the same time period and possibly associated with the two mortuary phases at Tablada. The cemetery is located on a desert plateau unsuitable for permanent settlements. Except for seasonal campsites from the Preceramic and Initial periods, there is no other evidence for temporary or permanent settlement occupations. It is likely the individuals buried in Tablada resided in the nearby valley of Lurín. Patterson et al. (1982) documented numerous post-Chavin and pre-Lima settlements smaller than 0.1 ha on average on both sides of the Lurín river, between the gorge of Atocongo, Quebrada and Sisicaya in the middle Lurín valley. The ceramic wares identified at those sites were a coarse Brown ware and a fine Orange ware (Patterson et al., 1982). These appear to be the ceramic wares also present in Tablada. However, Patterson's ceramic material was never published. It is therefore not possible to directly compare his findings to those in Tablada. If the comparison between the ceramic wares is valid, and given the extent of the Tablada cemetery, it seems likely that the people inhumed in Tablada also came from both sides of the valley, between the gorge of Atocongo, Quebrada, and Sisicaya in the middle Lurín valley.

Fig. 2. Individual burial from the first phase of occupation.

Neither of the funerary populations display grave goods linked with fishing, shellfishing, or the exploitation of other marine resources. Individuals from Phase 1 were buried facing the Andes (East). This contrasts with findings from other cemeteries in the same valley along the coast: Villa el Salvador, Ferrocarril, El Panel, and Lomo de Corvina. At these mortuary sites, individuals were

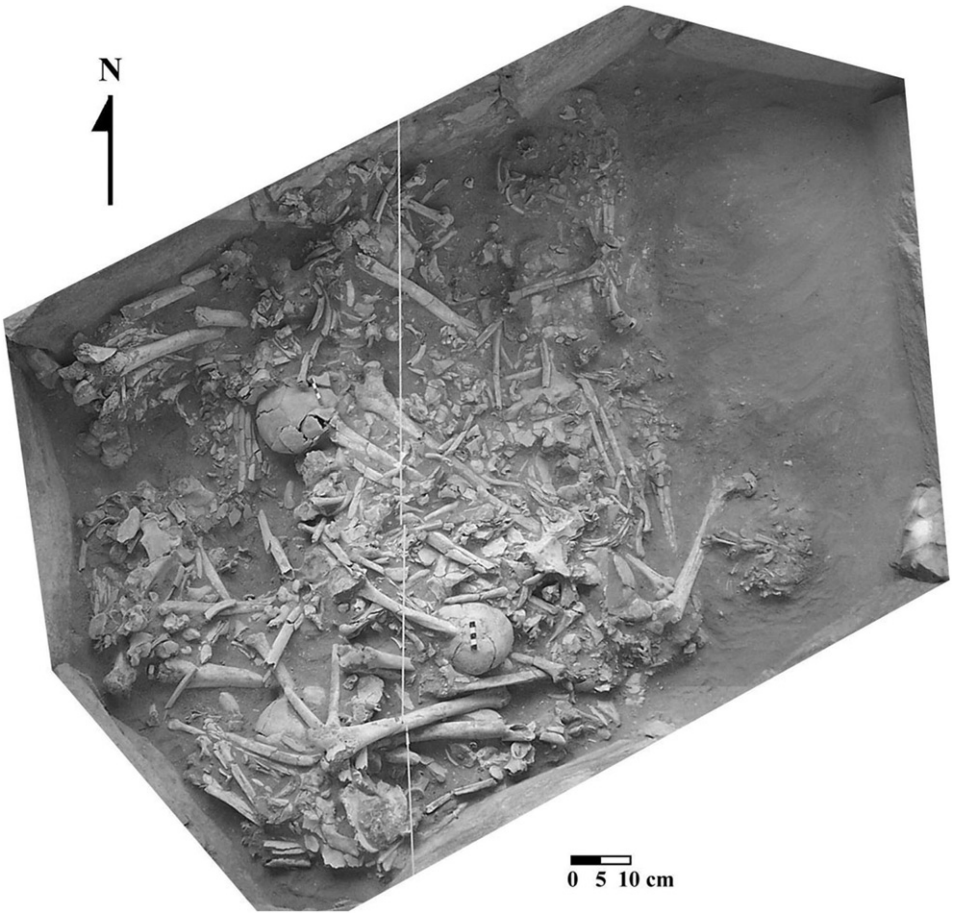

Fig. 3. Collective burial from the second phase of occupation.

Table 1
Human bone and tooth samples' collagen results yield, stable isotope ratios, and estimated marine protein intake (samples meeting international preservation criteria only (see text)).

Lab number	Material	Phase	Sex	Age	Structure	Specimen type	Associated samples (bone or tooth)	%N	%C	C/N	δ^{15}N AIR (‰)	δ^{13}C PDB (‰)	Yield (mg/g)	%S	C/S	N/S	δ^{34}S CDT (‰)	Est. % marine food
H80	Bone	1	F	MA	94	Femur R	Hd27	15.8	45.3	3.3	15.7	−10.2	29.9	0.3	444.1	132.7	13.9	90
H84	Bone	1	F		46	Humerus R	Hd46	14.2	40.8	3.3	15.2	−13.4	41.2	0.2	613.3	182.8	12.9	62
H69	Bone	1		6	87 (ind 2)	Humerus L		12.0	35.7	3.5	13.3	−13.7	8.6					60
H75	Bone	1		7	219	Femur R		11.3	33.2	3.4	14.8	−9.7	6.6					94
Hd47	Dentin	1	F	MA		M2 sup R	H55	14.8	41.8	3.3	15.6	−10.6	104.9	0.2	547.5	166.5	13.9	86
Hd29	Dentin	1	F			M2 sup L	H83	12.4	37.2	3.5	15.3	−9.9	16.9					92
Hd46	Dentin	1	F			M2 sup L	H84	14.5	41.1	3.3	14.7	−12.4	90.8	0.2	591.5	179.1	12.2	70
Hd33	Dentin	1	M	YA		M2 in. L	H52, Hde33	14.7	41.0	3.2	14.2	−13.3	106.0	0.2	545.3	167.6	13.1	63
Hd42	Dentin	2			EF 1	M2 in. L		13.3	37.6	3.3	14.6	−10.3	69.1	0.2	504.6	153.0	13.6	89

buried facing the sea (West), together with marine goods (*e.g.*, shellfish) (Maguiña and Paredes, 2009; Pechenkina and Delgado, 2006).

1.2.1.1. Phase 1. The work of all research projects on site since the late 1950s has led to the excavation of 859 pit burials. Burials were mostly single interments and contained both juveniles and adults. Occasionally a burial was reused for one or two subsequent individuals. The burial pattern was the same for males and females, juveniles and adults, and burial accoutrements indicate some social differentiation among members of society (Makowski et al., 2012).

During Phase 1, the cemetery was arranged in large clusters, which in turn were composed of smaller clusters of burials[2]. The demographic make-up of the smaller clusters is representative of that of the larger clusters; that is, both kinds of clusters contain juveniles and adults, males and females in similar proportions. It is thought that the smaller clusters represent family groups, possibly extended, whereas the larger ones – formed by several small clusters – represent villages or tribal groups. As mentioned, due to the large size of the cemetery, it is likely several villages or groups shared the site and hence a common funerary rite (Makowski et al., 2012). Whether these different communities were specialised like in Rostworowski's (1970, 1977a, 1977b) model, or whether they subsisted through a system of ecological complementarity (Murra 1972 in Murra, 1975) remains to be established.

1.2.1.2. Phase 2. This phase follows immediately from Phase 1 both chronologically and stratigraphically. There is no break in the sequence of use of the mortuary site. However, the burial pattern changes. The single pit burials are replaced by collective funerary semi-subterranean structures that contained 20 to 45 commingled individuals (Fig. 3; Gerdau, 2007). A total of 35 structures have been excavated since the late 1950s. The structures contained primary and secondary burials. Certain individuals had been buried in the structures before the decomposition process was advanced (primary deposits). Others had arrived as secondary deposits, their skeletonised remains laid to rest in the structures (Balbuena Cotlea, 1996; Gerdau, 2007; Gerdau and Makowski, 2011). The long-term use, large concentration of individuals and constant manipulation of the remains in the restricted space of these structures (up to 45 individuals in 2 m^2), led to heavy commingling and fragmentation of the remains (Gerdau, 2007; Gerdau and Makowski, 2011). This contrasts with the better preservation of the Phase 1 individuals.

[2] For an image of the spatial arrangement of the burials, please see Figs. 2 and 3 in Makowski et al., 2012.

All individuals, male and female, young and old, were subject to the same burial ritual. Funerary accoutrements were sparse and only a few were clearly associated with certain individual deposits. It is therefore difficult to make suggestions as to social differentiation among individuals buried during Phase 2, or as to sex or age differences in burial treatment. Notwithstanding, the funerary accoutrements present were similar to those from Phase 1. In themselves, these accoutrements do not appear to indicate cultural or subsistence differences between the two phases of mortuary use at Tablada. The difference between the phases is only evident in the change of burial practice and funerary architecture: from individual to collective, from pit burials to semi-subterranean stone chambers.

1.3. Aim and objectives

Given the material findings at Tablada and the potential relationship between burial location and environmental exploitation, the aim of this study was to test the following hypotheses through multi-element isotopic analysis:

1. Both funerary populations consumed mainly animal protein of terrestrial and not marine origin.
2. Both populations had similar diets.
3. Both populations had similar geographic origins and came from the middle Lurín valley.

The study also sought to investigate whether stable isotope data in combination with archaeological material evidence could shed light on the economic subsistence model of both funerary populations at Tablada.

1.4. Stable isotopes, diet and mobility

Bone, dentine, and enamel have different composition and growth patterns. Bone and dentine are composed of organic (collagen) and mineral (bioapatite) matter allowing the study of various chemical elements according to the component part analysed (Ambrose and Norr, 1993). Bone remodels throughout life and the turnover velocity depends on different physiological factors. The age of the individual plays an important role. Within normal health conditions, the younger the subject, the faster the growth and remodelling (ICRP, 2002; Hedges et al., 2007). Consequently, chemical components studied in immature bone reflect information closer to the time of death than in adult bone matter (Hedges et al., 2007).

On the contrary, tooth once formed does not remodel and therefore informs on the specific moment of growth. Enamel and dentine are mainly composed of mineral matter (96% and 72% respectively; Hillson, 2005). Enamel's crystalline structure makes it generally more resistant to diagenetic processes (Hedges et al., 1995). The

Table 2
Apatite bone and tooth samples' stable isotope ratios, estimated C_4 intake in total diet, and estimated origin of drink water. Tooth and bone samples from the same individual are shown in the same row. 'Est. % C_4 plants': estimate of C_4 plant proportion in the diet according to Ambrose et al. (1997, 2003). 'Anth. Drinks': Anthropic drinks and/or cooked products.

Sample Number Bone	Phase	Sex	Age	Structure	Specimen type and number	$\delta^{13}C_{ap}$ PDB (‰)	$\delta^{18}O_{ap}$ PDB (‰)	$\delta 1^8O_{dw}$ SMOW (‰)	Est. % C_4 plant	$\delta^{18}O_{dw}$ est. origin
H1	2	M		EF 2	Coxal 347	−5.6	−1.1	−1.3	67	Anth. drinks/Contamination?
H3	2	M		EF 4	Coxal 1319	−6.1	−2.6	−3.8	63	Coast
H8	2	F		EF 3	Coxal 601	−5.5	−1.6	−2.3	67	Anth. drinks/Contamination?
H9	2	F		EF 3	Coxal 769	−4.4	−1.6	−2.2	75	Anth. drinks/Contamination?
H10	2	F		EF 4	Coxal 2807	−4.4	−0.9	−1	74	Anth. drinks/Contamination?
H11	2	F		EF 4	Coxal 2840	−6.7	−0.7	−0.7	60	Anth. drinks/Contamination?
H12	2	F		EF 1	Coxal 818	−7.4	−0.9	−1	55	Anth. drinks/Contamination?
H14	2	F		EF 2	Coxal 282	−4.0	−0.4	−0.3	78	Anth. drinks/Contamination?
H15	2			EF 3	Femur 118	−6.3	−0.1	0.2	62	Anth. drinks/Contamination?
H16	2			EF 3	Femur 1064	−3.6	−0.7	−0.8	80	Anth. drinks/Contamination?
H17	2		<14	EF 4	Femur 4442 (Ind XV)	−4.9	−0.8	−1	72	Anth. drinks/Contamination?
H19	2			EF 2	Femur 20	−7.2	−0.2	0.1	56	Anth. drinks/Contamination?
H20	2			EF 2	Femur 883	−8.8	−0.8	−0.9	45	Anth. drinks/Contamination?
H21	2			EF 1	Femur 1573	−5.9	−1.0	−1.2	65	Anth. drinks/Contamination?
H22	2			EF 1	Femur 1629	−5.9	−1.3	−1.6	65	Anth. drinks/Contamination?
H52	1	M	YA	191 (Ind 1)	Femur R	−5.5	−0.4	−0.2	67	Anth. drinks/Contamination?
H53	1	F	18	525	Femur R	−5.5	−1.0	−1.2	67	Anth. drinks/Contamination?
H54	1	F	MA	42 (Ind 1)	Femur	−4.7	−1.7	−2.4	73	Anth. drinks/Contamination?
H55	1	F	MA	172 (Ind 2)	Tibia R	−7.2	−1.0	−1.2	56	Anth. drinks/Contamination?
H56	1	M	MA	336	Tibia L	−5.9	−0.4	−0.2	65	Anth. drinks/Contamination?
H57	1	M		298	Femur L	−5.7	−0.4	−0.3	66	Anth. drinks/Contamination?
H58	1	M		20	Femur R	−4.3	−1.3	−1.8	75	Anth. drinks/Contamination?
H59	1	M	MA	29	Femur L	−4.8	−0.9	−1.1	72	Anth. drinks/Contamination?
H60	2		C	EF 6	Femur 272 (group P)	−3.2	−1.0	−1.2	82	Anth. drinks/Contamination?
H61	1	M	YA	38	Femur R	−4.9	−0.3	−0.1	72	Anth. drinks/Contamination?
H62	1	M	YA	128	Tibia R	−4.4	−0.9	−1.1	75	Anth. drinks/Contamination?
H63	2	F		EF 6	Coxal 252	−4.9	−1.6	−2.2	71	Anth. drinks/Contamination?
H64	2	F		EF 6	Coxal 376	−5.0	−1.2	−1.5	70	Anth. drinks/Contamination?
H65	1	M	MA	68	Femur L	−8.1	−2.7	−4.1	50	Coast
H66	1		6	130	Femur R	−4.8	−0.7	−0.7	72	Anth. drinks/Contamination?
H67	1		8	72 (Ind 1)	Tibia I	−6.3	−0.4	−0.3	62	Anth. drinks/Contamination?
H68	1		7	84 (Ind 2)	Femur R	−5.3	−1.1	−1.4	68	Anth. drinks/Contamination?
H69	1		6	87 (Ind 2)	Humerus L	−8.6	0.9	1.9	47	Anth. drinks/Contamination?
H70	1		6	103 (Ind 2)	Femur L	−5.3	−0.4	−0.2	68	Anth. drinks/Contamination?
H71	1		7	253	Tibia L	−6.0	0.7	1.6	64	Anth. drinks/Contamination?
H72	1		12	145 (Ind 3)	Femur R	−3.8	−1.1	−1.3	79	Anth. drinks/Contamination?
H73	1		8	135	Femur R	−5.2	−0.2	0.1	70	Anth. drinks/Contamination?
H74	1		8	156	Femur L	−6.1	−0.5	−0.3	64	Anth. drinks/Contamination?
H75	1		7	219	Femur R	−4.3	−0.5	−0.4	76	Anth. drinks/Contamination?
H76	1	M	MA	68 (Ind 1)	Femur L	−4.8	−1.1	−1.5	72	Anth. drinks/Contamination?
H77	1	M	MA	331	Femur R	−8.1	−2.5	−3.7	50	Coast
H78	1	F	17	48	Femur L	−5.8	0.4	1	65	Anth. drinks/Contamination?
H79	1	F	MA	55 (Ind1)	Femur L	−5.7	−2.0	−2.9	66	Anth. drinks/Contamination?
H80	1	F	MA	94	Femur R	−5.9	−1.0	−1.2	65	Anth. drinks/Contamination?
H81	1	F		147	Femur L	−4.8	−1.3	−1.7	72	Anth. drinks/Contamination?
H82	1	F		160	Femur L					
H83	1	F		312	Humerus L	−6.4	−0.6	−0.5	61	Anth. drinks/Contamination?
H84	1	F		46	Humerus R	−8.3	−0.2	0	49	Anth. drinks/Contamination?

Sample Number Bone	Phase	Structure	Sample Number Dentine	Specimen type	$\delta^{13}C_{ap}$ PDB (‰)	$\delta^{18}O_{ap}$ PDB (‰)	$\delta 1^{8}O_{dw}$ SMOW (‰)	Est. % C_4 plant	$\delta^{18}O_{dw}$ est. origin	Sample Number Enamel	$\delta^{13}C_{ap}$ PDB (‰)	$\delta^{18}O_{ap}$ PDB (‰)	$\delta 1^{8}O_{dw}$ SMOW (‰)	Est. % C_4 plant	$\delta^{18}O_{dw}$ est. origin
H52	1	191 (Ind 1)	Hd33	M2 inf L	−7.5	0.0	0.5	54	Anth. drinks/Contamination?	Hde33	-5.3	-2.1	-3	69	Anth. drinks/Contamination?
H53	1	525	Hd24	M2 sup L	−5.0	−0.8	−1	71	Anth. drinks/Contamination?						
H54	1	42 (Ind 1)	Hd45	M2 sup L	−4.2	−0.9	−1	76	Anth. drinks/Contamination?						
H55	1	172 (Ind 2)	Hd47	M2 sup R	−5.8	0.2	0.8	66	Anth. drinks/Contamination?	Hde47	-4.3	-1.5	-2.1	75	Anth. drinks/Contamination?
H56	1	336	Hd36	M2 sup L	−6.3	−0.7	−0.7	62	Anth. drinks/Contamination?						
H57	1	298	Hd34	M2 sup L	−7.2	0.1	0.5	56	Anth. drinks/Contamination?						
H58	1	20	Hd30	M2 sup L	−9.8	−5.9	−9.3	38	Mountain						
H59	1	29	Hd31	M2 inf L	−6.5	−0.6	−0.5	61	Anth. drinks/Contamination?						
H60	2	EF 6													
H61	1	38	Hd32	M2 sup L	−6.0	−1.0	−1.3	64	Anth. drinks/Contamination?						
H62	1	128	Hd49	M2 sup R	−4.8	−1.2	−1.6	72	Anth. drinks/Contamination?	Hde49	-2.4	-1.7	-2.3	88	Anth. drinks/Contamination?
H63	2	EF 6													
H64	2	EF 6													
H65	1	68	Hd51	M2 sup L	−7.7	−1.9	−2.8	53	Anth. drinks/Contamination?						
H66	1	130													
H67	1	72 (Ind 1)													
H68	1	84 (Ind 2)													
H69	1	87 (Ind 2)													
H70	1	103 (Ind 2)													
H71	1	253													
H72	1	145 (Ind 3)													
H73	1	135													
H74	1	156													
H75	1	219													
H76	1	68 (Ind 1)	Hd50	M2 sup R	−5.7	−1.7	−2.3	66	Anth. drinks/Contamination?						
H77	1	331	Hd35	M2 sup L	−8.3	−2.8	−4.2	49	Coast						
H78	1	48	Hd25	M2 sup L	−4.9	−0.6	−0.6	72	Anth. drinks/Contamination?						
H79	1	55 (Ind1)	Hd26	M2 inf L	−5.7	−1.2	−1.6	66	Anth. drinks/Contamination?						
H80	1	94	Hd27	M2 sup L	−6.3	−2.3	−3.4	62	Coast						
H81	1	147	Hd23	M2 sup L	−4.3	−1.3	−1.6	75	Anth. drinks/Contamination?						
H82	1	160	Hd28	M2 sup L	−10.2	−5.8	−9.1	36	Mountain						
H83	1	312	Hd29	M2 sup L	−4.3	−0.3	−0.1	75	Anth. drinks/Contamination?						
H84	1	46	Hd46	M2 sup L											
	2	EF 4	Hd37	Cranium 3743 (M2 sup L)	−3.9	−0.9	−1	78	Anth. drinks/Contamination?						
	2	EF 1	Hd38	Cranium 511 (M2 sup L)	−5.6	−0.3	−0.1	67	Anth. drinks/Contamination?	Hde38	-7.0	-0.9	-1	57	Anth. drinks/Contamination?
	2	EF 1	Hd39	Cranium 448 (M2 sup R)	−5.8	−0.4	−0.2	65	Anth. drinks/Contamination?						
	2	EF 1	Hd40	Mandible 551 (M2 inf L)	−5.5	−0.8	−0.8	67	Anth. drinks/Contamination?						
	2	EF 1	Hd41	Mandible 2 (ind 11?) (M2 inf L)	−6.2	−1.3	−1.7	62	Anth. drinks/Contamination?						
	2	EF 1	Hd42	Mandible 55 (M2 inf L)	−5.0	0.2	0.7	71	Anth. drinks/Contamination?						

analysis of organic and mineral matter from both bone and tooth offers information on an individual's early and late years, enabling the identification of dietary changes and geographic migration throughout life, particularly in adults. However, within teeth, secondary dentine continues to form throughout life within the pulp chamber and root canals (Hillson, 2005). It is difficult, however, to distinguish between primary and secondary dentine (Mjör et al., 2001). Furthermore, secondary dentine apposition does not occur in a linear manner (Meinl et al., 2007).

There are two models for how carbon is incorporated into bone collagen and apatite (Ambrose et al., 2003; Schwarcz, 2002): the Linear Mixing model (Scrambled Egg) and the Macronutrient Routing model. On the one hand, according to the Linear Mixing model, carbon is incorporated equally into collagen and apatite from all dietary sources (protein, lipid, and carbohydrates). On the other hand, the Macronutrient Routing model proposes that carbon from protein is mainly incorporated into bone collagen, and that carbon from fat and carbohydrates is mainly incorporated into bone apatite. Ambrose et al. (2003) estimate that the routing of protein carbon into collagen is 65%, whereas Fernandes et al. (2012) estimate it at 75%. If the Macronutrient Routing model is correct, then in populations who heavily rely on maize, maize should be underrepresented in collagen as it has a low protein content (*ca.* 10%) (Ambrose et al., 2003; Schwarcz, 2002). Consequently, in a Macronutrient Routing model, stable isotope analysis of collagen is not a good indicator of total diet, and needs to be considered alongside the apatite data. Nitrogen in collagen, however, is routed from protein, and therefore informs about an individual's protein intake (Ambrose and Norr, 1993; Ambrose et al., 2003).

Plant food items at the base of the food chain have isotopic values that vary in accordance with the type of photosynthesis, the environment and the species. These isotopic differences have an impact throughout the food chain, at each step becoming enriched in heavy isotopes. The isotopic shift observed between diet and collagen is *ca.* 5‰ (Ambrose and Norr, 1993), or possibly 6‰ according to some authors (O'Connell et al., 2012) when analysing a monoisotopic diet (Ambrose et al., 2003). The shift recorded between the collagen from consecutive trophic levels (*e.g.*, between a herbivore and a carnivore) is usually around +1.0‰ for $\delta^{13}C$ and between +3.0 and 5.0‰ for $\delta^{15}N$ (Bocherens and Drucker, 2003; DeNiro and Epstein, 1978; Minagawa and Wada, 1984). However, to interpret the results it is necessary to characterise the isotopic environment of the human population. Therefore faunal remains with well-known diets present at the site have to be included in the analysis (Herrscher and Le Bras-Goude, 2010).

In plants, the isotopic signature of $\delta^{34}S$ is linked to the levels of soil sulphates, which vary in accordance with the geological terrain, erosion, microbial soil activity, and local atmosphere (*e.g.*, sea spray; Krouse et al., 1991). Isotopic fractionation is considered negligible between the soil sources and plants as well as between any of the links in the food chain. Nevertheless, $\delta^{34}S$ values are relatively high in a sea environment (+20.0‰) and more variable in a land and freshwater environment (−10 to +20‰; Nehlich, 2009). Consequently, measured in collagen, $\delta^{34}S$ can inform on an individual's local diet and possibly habitat, if individuals close to the sea are consuming either more seafood or herbivores raised by the seaside, which in turn eat plants covered by sea spray. Sulphur can therefore help distinguish those close to a marine environment from those further inland. If the geological regions are isotopically different, it can also further discriminate between geographic origins (Oelze et al., 2012; Vika, 2009).

In bone and tooth apatite, $\delta^{13}C_{ap}$ and $\delta^{18}O$ can be measured in calcium carbonate. Apatite carbonate is derived from inorganic carbon dissolved in blood (Passey et al., 2005). Apatite $\delta^{13}C_{ap}$ reflects the global energy consumed (Ambrose and Norr, 1993). Diet-apatite carbon isotope spacing is different according to species (*e.g.* Passey et al., 2005). The one used for humans varies slightly according to different authors. We consider data proposed by Ambrose et al. (2003), Ambrose and Krigbaum (2003), and Hu et al. (2006) indicating an isotopic shift between diet and apatite of *ca.* 9.4‰. Carbon apatite–collagen ($\delta^{13}C_{ap-co}$) spacing can be used to estimate the trophic level (Ambrose et al., 2003; Hedges, 2003; Krueger and Sullivan, 1984). However, in the case of wide isotopic variability of resources consumed (*i.e.* C_3, C_4, marine environments), it is mainly used to estimate dietary components. As proposed by Ambrose et al. (2003), $\delta^{13}C_{ap-coll}$ can vary from >11‰ when C_3 protein and C_4 non-protein are consumed to *ca.* 0‰ conversely.

Oxygen ($\delta^{18}O$) in bone mineral reflects the $\delta^{18}O$ of water ingested, mainly by beverage (Longinelli, 1984). Human drinking water comes mainly from springs and other natural sources. Human $\delta^{18}O$ reflects the $\delta^{18}O$ of meteoric water, which varies according to different parameters, such as temperature, altitude, and latitude. Therefore, and under certain conditions, human $\delta^{18}O$ can be used to determine geographic origins (*e.g.*, White et al., 1998).

2. Sampling strategy and analyses

Sampling was performed on 49 human individuals and 11 individual sets of faunal remains from different species available on the site. Previous sampling of human remains for radiocarbon dating indicated poor survival of collagen. Therefore, to maximise the chances of extracting enough collagen, we chose to sample long bone fragments (compact bone) from ten females, ten males, ten juveniles (>four years old) from Phase 1 burials. Both teeth and bone from the same human individuals in Phase 1 were sampled.

Animal remains were chosen according to their presence in the burials because material was not available from contemporary settlements (taruca (*Hippocamelus antisensis*), alpaca (*Vicugna pacos*), llama (*Lama glama*), pelican (*Pelecanus* sp.), Andean condor (*Vultur gryphus*)). Nine different individual samples that would not be completely destroyed by the sampling procedure were chosen. We acknowledge that these animals may not necessarily be representative of everyday diet as they were included as grave offerings. Nevertheless, they still provide a baseline for interpreting the results.

Phase 2 individuals had been buried in collective commingled deposits. Given the commingling and MNI in the structures, it was not always possible to establish which skeletal elements pertained to one single individual, and to ascertain some of the biological information, such as sex and age-at-death, on selected material. For these reasons, ossa coxae were selected. Eight females, two males, two juveniles (>four years old), six individuals of unidentified sex, and two different samples from among the faunal remains (dog and taruca (*H. antisensis*)) were chosen.

Twenty of the sampled individuals from Phase 1 were available for sampling the root dentine of the second molar. Root dentine was sampled so that both collagen and apatite could be analysed and compared to the isotope yields from the bones of the same individuals. This would also allow for intra-individual comparisons. Three individuals among those 20 were also sampled on the crown enamel to test if it would be better suited to analyses in the future. From Phase 2, the second molars of six individuals were chosen. These six samples also included one individual sampled for crown enamel. The human samples are detailed in Tables 1 and 2.

In addition to the archaeological faunal set of remains, modern samples of foods locally consumed were also analysed. These included various fruit and vegetables, some fish and meat, and both C_3 and C_4 plants (Table 3). All material was prepared at the LAMPEA laboratory (UMR 7269, Aix-en-Provence, France). Bone

Table 3
Yield and stable isotope ratios for Peruvian modern food. Carbon isotope ratios have been corrected due to the "fossil fuel effect" (Marino and McElroy, 1991). Some carbon isotope ratios are not reported due to lipid content (vegetal oil) in fish preparations (DeNiro and Epstein 1977).

Species	%N	%C	$\delta^{15}N$ (‰)	$\delta^{13}C_{corr}$ (‰)	%S	$\delta^{34}S$ (‰)
Potato (*Solanum tuberosum*)[a]	1.1		4.1	−28.1		
Potato (*Solanum stenotomum* ssp. *goniocalyx*)[a]	2.0	41.0		−25.5		
Potato (*Solanum stenotomum* ssp. *goniocalyx*)[a]	0.6	41.8	10.3	−28.0		
Ground nut (*Arachis hypogaea*)[b]	4.8	55.3		−30.5		
Oca (*Oxalis tuberosa*)[b]	0.4	34.0		−28.6		
Bean (*Phaseolus lunatus*)[b]				−26.8		
Bean (*Phaseolus vulgaris*)[b]	4.3	43.4	6.1	−27.2		
Quinoa (*Chenopodium quinoa*)[c]	2.4	42.8	3.3	−27.0		
Chilli (*Capsicum baccatum*)[b]	1.3	48.2	7.6	−30.0		
Camu-camu (*Myrciaria dubia*)[b]	1.7	43.8	4.5	−32.7		
Passion fruit (*Passiflora tripartita* va. *mollissima*)[b]	3.3	38.9	4.5	−29.2		
Pumpkin (*Cucurbita maxima*)[b]	2.1	39.3	6.4	−27.6		
Tomato (*Solanum lypopersicum*)[b]	2.3	40.0		−29.1		
"Stuffing cucumber" (*Cyclanthera pedata* (L) Schrad)[b]			5.2	−29.1		
Sweet potato (*Ipomoea batatas*)[a]				−28.5		
Manioc (*Manihot esculenta*)[d]	0.2	41.6	8.6	−27.9		
Rocoto (*Capsicum pubescens*)[b]	2.0	43.0		−30.5		
Avocado (*Persea americana*)[b]	0.6	65.9	4.7	−36.1		
Golden berry (*Physalis peruviana*)[b]	1.4	41.3	6.0	−26.4		
Papaya (*Carica papaya* L.)[b]	2.3	40.3	4.5	−26.9		
Sweet granadilla (*Passiflora ligularis*)[b]	3.7	36.0	8.2	−26.9		
Yellow passion fruit (*Passiflora edulis* f. *flavicarpa*)[b]			4.1	−28.5		
Alpaca (*Auchenia paco*)[e]	5.2	22.2	6.2	−26.5	0.8	15.2
Anchovy (*Engraulis ringens*)[f]			13.4		0.3	16.7
Jack mackerel (*Trachurus murphyi*)[f]			16.3		0.7	16.7
Mackerel (*Scomber japonicus*)[f]	14.0	48.9	11.4	−18.5	1.0	16.9
Sardine (*Sardinops sagax*)[f]			11.6		0.6	16.1
Maize (*Zea mays*)[c]	1.7	43.8	5.5	−13.6	0.1	7.4
Maize (*Zea mays*)[c]	1.4	43.4	2.8	−13.2	0.1	6.2
Maize (*Zea mays*)[c]	1.0	42.8	4.2	−13.5	0.1	5.8
Amaranth (*Amaranthus caudatus*)[c]	1.8	41.2	4.2	−14.5		

[a] Tuber.
[b] Fruit.
[c] Seed.
[d] Root.
[e] Dried/salted meat. The use of sea salt to dry the meat may explain the $\delta^{34}S$ result.
[f] Fish.

samples were cleaned with a sandblaster in order to efficiently remove the external surface of cortical bone, potentially altered. The surface of the tooth was cleaned with a drill and then in an ultrasonic bath to remove the remaining soil deposit. Collagen was extracted following Longin's (1971) and Bocherens's (1992) methods. The freeze-dried collagen and modern samples were analysed by EA-IRMS (Europa Scientific 20-20 IRMS, Iso-Analytical Ltd., UK) with reproducibility below 0.1‰ measurement error for C, N and 0.5‰ for S stable isotope ratios. The hydroxyapatite was purified according to Balasse et al.'s (2002) protocol. The carbonate was analysed in a Kiel IV Carbonate Device coupled to DeltaV Advantage IRMS, with a measurement error of 0.03‰ for C and of 0.07‰ for O.

3. Results

3.1. Collagen

The state of preservation of the archaeological collagen was checked according to international criteria: C/N between 2.9 and 3.6, %N ≥ 11, %C ≥ 30 (DeNiro, 1985; van Klinken, 1999); C/S between 300 and 900; and N/S between 100 and 300 (Nehlich and Richards, 2009). From the 87 samples, only 11 yielded sufficient collagen and only nine of those were well enough preserved to be included in the discussion below (three bone and six dentine samples). Among the nine samples, six had enough collagen to provide $\delta^{34}S$ isotopic values respecting standard preservation criteria. Only one human dentine sample from Phase 2 gave results. None of the faunal remains provided results adequate for an isotopic interpretation of the collagen values. They are therefore not included in Tables 1 and 2. All of this confirms that the collagen in the Tablada de Lurín series is poorly preserved.

The nine samples represent eight individuals because one individual presents both bone (H84) and dentine results (Hd46). Carbon ($\delta^{13}C$) and $\delta^{15}N$ stable isotope values range from −13.7‰ to −9.7‰ and from 13.3‰ to 15.7‰, respectively. Sulphur ($\delta^{34}S$) stable isotope values range from 12.2‰ to 13.9‰. Carbon ($\delta^{13}C$) and $\delta^{15}N$ are consistent with both marine and C_4 plant protein intake. However, proportions differ between individuals (Table 1; Figs. 4 and 5).

Using calculations proposed by Ambrose et al. (1997), the quantity of marine resources contributing to protein was estimated to range from 60% to more than 90% (Table 1). Since carbon in collagen mainly comes from dietary protein, it is likely these figures are slightly overestimated (Ambrose et al., 1997) and need to be considered alongside the apatite data. Furthermore, maize and beans may also be contributing some protein and consequently carbon into the collagen. The protein content of beans (*Phaseolus vulgaris*) is 20 to 26% (Barampama and Simard, 1993; Duranti, 2006) and of maize is *ca.* 10% (Ambrose et al., 2003). The limited sample size does not allow for statistical comparisons based on biological information. Nevertheless, there is variation in marine protein intake within the sample. The single male individual (Hd33) falls within the range of the female and juvenile samples. For one of the female individuals

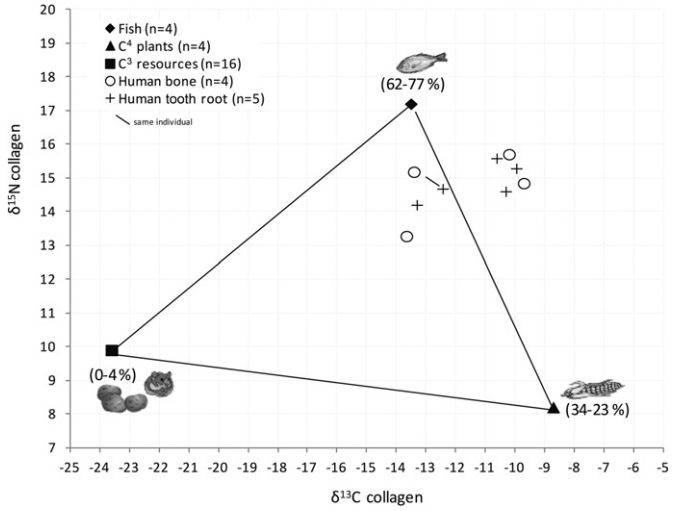

Fig. 4. Carbon and nitrogen stable isotope ratios of bone and dentine collagen, combined with concentration dependent mixing triangle (calculated from ISOCONC 1.01) and with concentration-weighted stable isotope mixing model (from IsoSource 1.3.1; Phillips and Koch, 2002).

(H84 and Hd46 samples), bone and dentine collagen was available for analysis. Data show that protein intake and food sources were similar in both childhood (dentine) and adulthood (bone) for this individual.

From the faunal remains one bone sample yielded results. Consequently, modern food values acquired for this study were used to generate a dietary model (Table 3; Ambrose et al., 1997; −1.6‰ for $\delta^{13}C$ in terrestrial ecosystem, −0.5‰ for $\delta^{13}C$ in marine ecosystem). IsoConc 1.01 (Phillips and Koch, 2002) and IsoSource 1.3.1 (Phillips and Gregg, 2003) were applied to generate the dietary model. Figs. 4 and 5 show that the human samples yielding collagen results cluster together and are closer to the marine food values than to the terrestrial food values.

3.2. Apatite

The apatite carbonate state of preservation in archaeological samples is difficult to estimate (Koch et al., 1997). Some data can be checked during the stable isotope measurement process in order to identify questionable samples (Zazzo, 2001). Most studies use enamel and/or the phosphate part of apatite, instead of bone or dentine carbonate. Enamel is less porous, which decreases the risk of isotopic modification induced by contamination and degradation (Koch, 2007; Koch et al., 1997; Wang and Cerling, 1994). However, in certain burial conditions, enamel can also be subject to alteration and show a modified isotopic signal (Koch, 2007; Zazzo et al., 2004). Carbon ($\delta^{13}C_{ap}$) and $\delta^{18}O$ analyses were performed on bone and dentine samples already used for collagen extraction, in order to combine both research objectives and to preserve the archaeological material as much as possible (thereby meeting the expectation of cultural heritage preservation authorities). In addition to bone and dentine, four enamel samples from the already sampled individuals were also analysed. All 87 samples gave isotopic results. Carbon ($\delta^{13}C_{ap}$) ranges from −15.0‰ to −2.4‰, with a mean of −6.2 and a standard deviation (SD) of 2.1. Oxygen ($\delta^{18}O$) ranges from −5.9‰ to +3.1‰ with a mean of −0.8 and a SD of 1.3 (Table 2).

3.2.1. Oxygen stable isotope

Palaeoclimatic research shows that environmental conditions along the Peruvian central coast have remained stable for the last 3000 years (Sandweiss, 2003; Sandweiss et al., 1998, 2007). Current precipitation values are therefore relevant to interpret the variation in oxygen stable isotope from drinking water ($\delta^{18}O_{dw}$) during the last 3000 years. The transformation of human $\delta^{18}O$ values to $\delta^{18}O_{dw}$ was performed following Friedman and O'Neil (1977), Chenery et al. (2012), and Daux et al. (2008). These transformations are complementary. Friedman and O'Neil's (1977) equation changes the standard from $\delta^{18}O$ PDB of carbonate to $\delta^{18}O$ SMOW ($= 1.03086 \times \delta^{18}O_c$ PDB + 30.86). Chenery et al.'s (2012) equation transforms the $\delta^{18}O$ SMOW values of carbonate into $\delta^{18}O$ SMOW values of phosphate ($= 1.0322 \times \delta^{18}O_c$ SMOW − 9.6849). Finally, Daux et al.'s (2008) equation transforms $\delta^{18}O$ SMOW values of phosphate into $\delta^{18}O_{dw}$ SMOW ($= 1.54 \times \delta^{18}O_p$ SMOW − 33.72). Results range from −9.3‰ to +1.9‰ (Table 2).

3.2.2. Carbon stable isotope

Using calculations proposed by Ambrose et al. (1997, 2003), the quantity of C_4 plants (mainly maize) contributing to the whole energy consumed was estimated (%C_4 = (−25 −

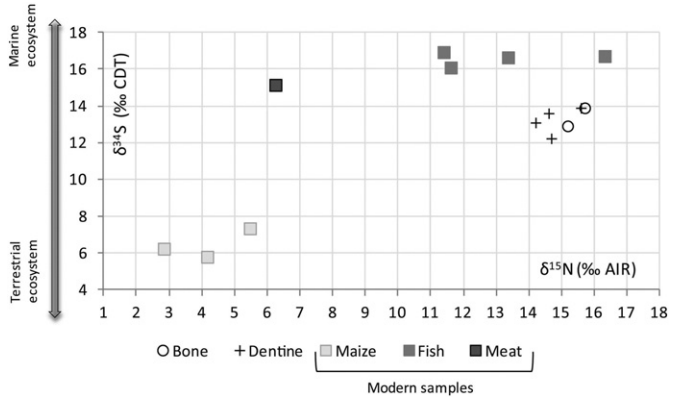

Fig. 5. Nitrogen and sulphur stable isotope ratios of bone and dentine collagen from Tablada archaeological samples and from modern food samples.

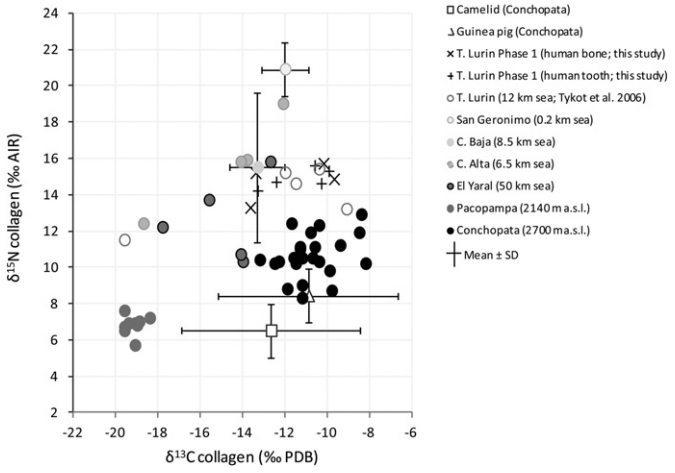

Fig. 6. Carbon and nitrogen stable isotope ratios from sites located at different altitudes in Peru (from Finucane et al., 2006; Knudson et al., 2007; Tomczak, 2003; Tykot et al., 2006) compared with data from this study.

($\delta^{13}C_{ap} - 9.4$)) / 15 × 100; Table 2). It ranges from 36% to 79% in the bone and dentine samples from Phase 1 without distinction between sexes or age groups. The difference between individual dentine and bone samples in the estimated proportion of C_4 plants contributing to the diet ranges from 37% to 0%. Most of the estimated differences are ≤15%, but one individual (samples H58 and Hd30) shows a difference of 37% between childhood (dentine) and adulthood (bone).

Results from the three enamel samples from Phase 1 indicate a high proportion of maize in total diet during childhood, yet the values are lower in the associated dentine. As mentioned in Section 1.4, teeth form during childhood and isotope content within the teeth reflects childhood diet. However, because there is a small amount of secondary dentine formed throughout life within the pulp chamber, and because the crown forms before the tooth root, enamel and dentine values may not be identical within the same individual. Here, the enamel values would indicate a greater proportion of maize in the diet during early childhood. Interestingly, for two individuals the proportions indicated by the bone apatite are greater than the dentine values, though still lower than the enamel values (H52 with Hd33 and Hde33: 67%, 54% and 69%; H62, with Hd49 and Hde38: 75%, 72% and 88%, respectively). This may be an indication of fluctuating proportions within the diet throughout the life course. From Phase 2, only one enamel sample (Hde38) yielded results and shows, contrary to Phase 1, a lower proportion of maize in early childhood diet when compared to the dentine sample of the same individual (Hd38): from 57% (enamel) to 67% (dentine).

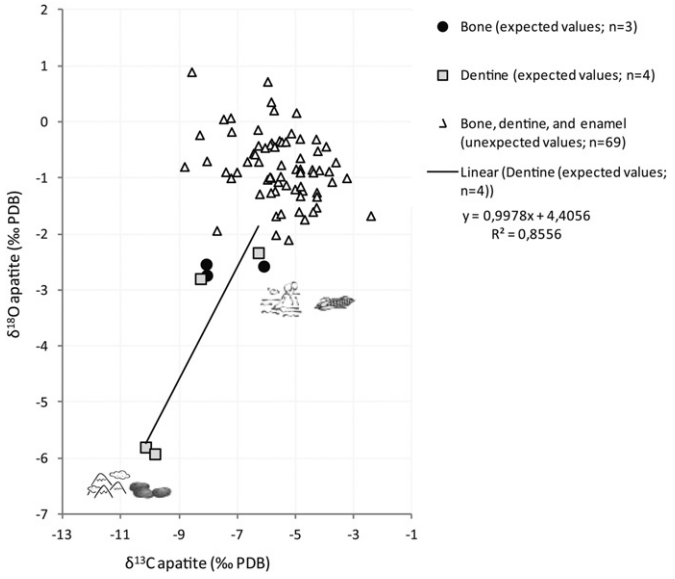

Fig. 7. Carbon and oxygen isotopic values from bone and dentine apatite and relationship with geographical origin of individuals.

4. Discussion

4.1. Collagen

The model in Fig. 4 was designed using modern food values acquired for this study and corrected for palaeodietary reconstruction (Ambrose et al., 1997; Phillips and Koch, 2002; Phillips and Gregg, 2003; Table 3). Results indicate a predominance of marine protein (possibly mixed with protein from maize and beans, and other carbohydrate and lipid sources) and relative importance of maize in the diet. Terrestrial C_3 resources (meat and plant) are not excluded but do not seem to feature prominently in the model produced.

From Phase 1, only one female individual yielded results suitable for intra-individual comparison — samples H84 and Hd46. Data show that her protein intake and food sources were similar between childhood (dentine) and adulthood (bone), indicating no or limited dietary changes during her lifetime (Table 1). From Phase 2, only one individual's dentine sample (Hd42) yielded results. This indicates a high proportion of marine protein contributing to the diet (89%; Table 1). As mentioned in Section 3.1, this is likely to be an overestimation of the marine protein intake as maize and beans also contribute protein to the diet. Furthermore, if the Macronutrient Routing model is correct, carbon in collagen is not a good indicator of total diet and needs to be considered alongside the apatite data (Ambrose et al., 2003). Finally, this one individual from Phase 2 had a similar dietary pattern in childhood to those recorded for Phase 1.

Comparisons with modern and archaeological $\delta^{34}S$ and $\delta^{15}N$ isotope values support the high contribution of marine protein to the diet in most individuals yielding results for analysis (Phase 1; Figs. 5 and 6). This is the first time $\delta^{34}S$ isotopic values from bone and tooth are proposed for Peruvian human palaeodietary research. Nevertheless, further analyses on other samples need to be conducted for a more accurate interpretation. Peru presents a strong altitudinal gradient, due to the Andes topography at the edge of the Pacific Ocean. It is possible the $\delta^{34}S$ coastal signal could be recorded far inland, if mountainous areas are reached by sea spray (*e.g.*, Zazzo et al., 2011). Plant and animal samples from different locations and environments should be studied in the future in order to better understand this phenomenon and interpret archaeological $\delta^{34}S$ values.

The results obtained were compared to previous ones from the same site (Tykot et al., 2006) and other pre-Columbian Peruvian sites (Finucane et al., 2006; Knudson, 2009; Knudson et al., 2007, 2009; Tomczak, 2003; Turner et al., 2009; Williams, 2005). The results fit with the conclusion proposed by Tykot et al. (2006: 195) on other individuals from Tablada de Lurín (all from Phase 1, except one sample from Phase 2),[3] where seafood and maize would have been the staple foods of the population (Fig. 6).

Distance to the sea seems to be an important factor in determining human dietary patterns in this region (Williams, 2005). Individuals found on sites located close to the ocean, such as Chiribaya Alta and Mina Perdida, show stable isotope values consistent with marine protein intake and maize consumption (hair and bone analysis; Knudson et al., 2007; Tomczak, 2003; Tykot et al., 2006). Further inland, a combination of C_3 and C_4 resources with less marine protein intake dominate the diet (*e.g.*, El Yaral, 1000 m a.s.l.; Knudson et al., 2007; Tomczak, 2003). Finally, individuals found on sites located at middle to high altitude, such as Pacopampa and Conchopata (>2000 m a.s.l.), show stable isotope values consistent with consumption of terrestrial resources including either large amounts of maize or large amounts of C_3 plants like potatoes (*Solanum tuberosum*; Finucane et al., 2006; Tykot et al., 2006).

The variation in marine protein intake of the Tablada series (Table 1) indicates slightly different dietary practices and possibly different geographical origins for the individuals sampled. The sulphur values suggest that individuals lived close enough to the

[3] This is not stated in Tykot's text, but the code for one of the samples indicates it comes from structure EF3 (Phase 2; Tykot et al., 2006: Table 14.1).

ocean and could possibly have been able to acquire fresh seafood on a regular basis. Therefore, the results from the individuals sampled at Tablada indicate they consumed marine protein on a regular basis; however, there is no evidence from the material goods for the regular practice of shellfishing, fishing, or the acquisition of other marine resources. Based on our findings and Tykot et al.'s (2006), we would like to suggest that the inhumed population at Tablada (at least for Phase 1) formed part of a larger group of people, who may have included, for example, the populations buried at El Panel, Ferrocarril, and Villa el Salvador. These other burial populations do show evidence for the acquisition of marine goods. This would suggest that these cemeteries may represent specialised groups, and therefore Rostworowski's (1970, 1977a, 1977b) proposed economic arrangement for the Peruvian coast during the early 16th century AD may apply as far back as the EIP to some coastal populations.

4.2. Apatite

4.2.1. Oxygen stable isotope

Although the samples respected all first analysis criteria (Zazzo, 2001), most of them show $\delta^{18}O$ values not consistent with values expected for inhabitants of this part of the Andes (Table 2; Fig. 7). Work performed by Knudson (2009) to test the validity of this stable isotope as an archaeological residential mobility tracer in the Andes, indicated a range of $\delta^{18}O$ from −10.6‰ to −1.8‰ and a $\delta^{18}O_{dw}$ from −14.9‰ to −3.6‰ (measured on archaeological enamel apatite). Since palaeoclimatic research indicates that environmental conditions along the Peruvian central coast have remained stable for the last 3000 years (Sandweiss, 2003; Sandweiss et al., 1998, 2007), current precipitation values are therefore relevant to understand the $\delta^{18}O_{dw}$ variability of Tablada's samples. The modern database proposed by Bowen (2011) and Bowen and Revenaugh (2003) indicates precipitation $\delta^{18}O$ values from *ca.* −4‰ (coast) to <−10‰ (high altitude) in this area. Moreover, research performed by the International Atomic Energy Agency (IAEA) on different water sources, in particular from the Lima aquifers (lake, river), indicates $\delta^{18}O$ values of *ca.* −10.5 ± 3‰ (IAEA, 2009).

Considering these data, most of the samples analysed here do not fit with the geographical area considered. Most of the values recorded are more consistent with the region of Tumbes (IAEA, 2009), located at the North of Peru, at the Ecuadorian border, *ca.* 1000 km away from the Lurín Valley. Though such long distance migration cannot be excluded, two other main explanations are considered: (1) the consumption of beverages with high $\delta^{18}O$ and/or (2) the strong alteration of carbonate and thus the modification of isotopic values. The regular consumption of beverages as brewed drinks (*e.g.*, beer), boiled drinks (*e.g.*, infused herbal beverages), or even stewed food would affect bone $\delta^{18}O$ (Brettell et al., 2012). Brettell et al.'s (2012) study demonstrates that a $\delta^{18}O$ shift occurs during different heating processes. The authors estimate that the regular consumption of a "cooked" beverage or soup would lead to a bone $\delta^{18}O$ increase between 0.6‰ and 4.4‰ compared to the regular consumption of freshwater. Similar results were found by Daux et al. (2008) on modern food with the highest modification recorded in vegetables. There is archaeological evidence, at least as far back as the EIP, and ethno-historic accounts from the Central Andes for the production and consumption of *chicha* (maize fermented drink; Dillehay, 2003; Hastorf and Johannessen, 1993; Jennings, 2014; Rostworowski, 1977b: 240–244; Segura, 2001; Shimada, 1994: 221–224). At Tablada, such behaviour must be taken into consideration. Nevertheless, considering the poor preservation of collagen in the samples, it is also possible the $\delta^{18}O$ values have been altered due to diagenetic processes.

Some authors use isotopic deviations between enamel and dentine tissues to detect diagenetic modifications (Hu et al., 2006; Zazzo, 2001). In the Tablada material (four samples), the difference of $\delta^{18}O$ recorded in enamel and dentine ranges from 0.35‰ to 2.31‰ (Table 2). However, the second molar crown and root mineralise at different times; human mobility during this time can therefore not be excluded. It appears, consequently, that using $\delta^{18}O$ to trace mobility patterns is not conclusive for the Tablada material. In this instance, all explanations – mobility, consumption of boiled/brewed water, and diagenetic changes – are equally valid.

4.2.2. Carbon and oxygen stable isotopes

Following the discussion above on the $\delta^{18}O$ results, 44 bone and 21 tooth samples have been excluded from the discussion due to questions about their preservation (Fig. 7). The seven other samples (representing five individuals from Phase 1 and one from Phase 2) can be discussed for both $\delta^{13}C_{ap}$ and $\delta^{18}O$ results: three bone and four dentine samples (underlined in Table 2). The calculated $\delta^{18}O_{dw}$ ranges from −9.32‰ to −3.4‰ and the $\delta^{13}C_{ap}$ from −10.2‰ to −6.1‰.

Among the $\delta^{18}O$ results, there are five samples, corresponding to four individuals, which have $\delta^{18}O$ readings consistent with a geographical location close to the sea (around 60 m a.s.l.; mean $\delta^{18}O$ values of precipitation = −5.0‰ (Bowen, 2011); bone samples: H3, H65, and H77 (and his dentine sample Hd35); dentine sample: Hd27; Table 2). Two other individuals, a female and a male (dentine samples Hd28 and Hd30, respectively; Table 2), yielded values similar to those expected for people who grew up at high-altitude (around 3000 m a.s.l.; mean $\delta^{18}O$ values of precipitation = −10.6‰ (Bowen, 2011)).

For the six individuals represented by these seven samples, $\delta^{13}C_{ap}$ variability indicates different C_4 consumption levels. Proportions range from 36% to 63% in the bone and the dentine samples of the six individuals. This variation fits with the $\delta^{18}O$ variation of the seven samples that yielded $\delta^{18}O$ readings consistent with either a coastal or mountainous location. The samples with the lowest $\delta^{18}O$ readings (dentine samples: Hd28 and Hd30) also recorded the lowest $\delta^{13}C_{ap}$ measurements among these seven samples (Table 2; Fig. 7).

The $\delta^{13}C_{ap}$ readings of dentine samples Hd28 and Hd30, which have $\delta^{18}O$ values consistent with a mountainous location, indicate less maize consumption (<40%; Fig. 7) than the four individuals with $\delta^{18}O$ 'coastal' readings (≥49% in their bone and dentine samples when available). This may mean that more C_3 resources contributed to the diet of these two individuals in childhood than to that of the other people. Furthermore, individual H58 (Hd30) almost doubled the estimated proportion of C_4 plants in his diet between childhood (estimated at 38%; dentine Hd30) and adulthood (estimated at 75%; bone H58), a difference of 37%. The difference in C_4 plant consumption through his life course could be the result of migration. His dentine $\delta^{18}O$ values are consistent with a mountainous location in childhood. Unfortunately, his bone $\delta^{18}O$ values cannot be interpreted. Bone sample H82 associated with Hd28 was unexploitable and therefore intra-individual comparisons cannot be made for that individual with regards to her diet.

The individual represented by samples H77 and Hd35 shows an estimated C_4 consumption of 49 and 50%, which indicates no modification in the levels of C_4 plants in his diet through his life course. His oxygen readings from both his bone and dentine samples are consistent with a coastal environment. Maize requires intensive irrigation and though it can be cultivated up to 3600 m a.s.l. (Perry et al., 2006), C_3 plants like the potato and other tubers are better suited than maize to these higher altitudes. Hawkes (1990 in Pearsall, 2008: 107) indicates that at the time of Spanish

conquest the potato was grown from 2000 to 4000 m a.s.l. Today the potato predominates between 1500 and 3500 m a.s.l. (Córdova, 2002: 250). In the archaeological record, iconography, plant remains and food residues show that from 2000 BC onwards a variety of crops were successfully cultivated on the Peruvian coast — including maize, potatoes, and other C_3 plants (Daunay et al., 2007; Janick, 2011; Pearsall, 2008: 116; Thompson, 2006; Ugent et al., 1982). It may be difficult from these archaeological sources to ascertain whether a crop was more important than another in terms of diet. However, studies of diet through stable isotope analysis show that coastal populations tended to consume more maize than their non-coastal counterparts (Burger and Van der Merwe, 1990; Tykot et al., 2006). It is therefore plausible that the individual represented by samples H58 and Hd30 increased his consumption of maize when he moved from a mountainous location to a site closer to the sea, but, as already mentioned, the oxygen results from his bone sample are unexploitable. The individual represented by samples H77 and Hd35 may have migrated during his lifetime but seemingly within a coastal setting and without changing his levels of C_4 plant consumption. No sex or age differences have been recorded among this small dataset and intra-individual comparisons rely solely on the individuals mentioned above.

5. Conclusion

This multi-element and multi-tissue study combines for the first time in the Peruvian Andes the usual isotopic data – $\delta^{13}C$, $\delta^{15}N$, and $\delta^{18}O$ – with $\delta^{34}S$ and modern samples. Though a limited number of samples yielded isotope data, results support a more complex dietary pattern than initially assumed by the study of the archaeological material and corroborate trends in Andean dietary patterns that have emerged from previous studies.

Notwithstanding the lack of evidence from the archaeological material for fishing or the exploitation of other marine resources by individuals buried at Tablada, it appears from the isotope analysis (collagen) that at least for Phase 1, seafood and maize constituted the staple foods. Their proportions vary according to each individual without the possibility of establishing, for the moment, a relationship with other biological or social data because of the limited sample size. Whether these variations could reflect differential access to *chicha* beer and marine food in relation to status, age, gender, or geographic origin, or just different eating practices among individuals and different origins for people from Phase 1 is yet to be answered. Furthermore, the results obtained from collagen are in line with those from previous studies (Finucane et al., 2006; Knudson, 2009; Knudson et al., 2007, 2009; Tomczak, 2003; Turner et al., 2009; Williams, 2005), particularly Tykot's results from Tablada (Tykot et al., 2006). From these studies, it appears that populations from sites close to the sea (<50 km) consume more marine protein and C_4 plants, as opposed to sites further inland where populations have a preference for terrestrial protein and C_3 plants (Fig. 6).

Results from the apatite do not contradict the collagen findings for $\delta^{13}C$. Intra-individual studies of the apatite results were only possible on one individual. This individual alongside the other five bone and dentine samples whose oxygen results could be interpreted (Table 2) highlighted once again the relationship between the coast and the consumption of C_4 plants, and the highlands and the consumption of C_3 plants.

Though archaeological remains of plants, food residue, and iconography can help ascertain which plants were cultivated or gathered and which animals were reared or hunted, it may be difficult from these sources to determine which were the actual staple foods of a population. Stable isotope analysis of human tooth and bone samples can help identify these staple foods as demonstrated through this study.

The $\delta^{18}O$ results emphasise the need for further studies in the region, in particular the question of brewed or boiled beverage consumption. Given Knudson's (2009) and Brettell et al.'s (2012) findings, the $\delta^{18}O$ results from Tablada cannot be explained solely by migration from the North coast or by diagenetic changes to the samples.

Our findings coupled with those from Tykot et al. (2006) suggest that the inhumed population at Tablada (at least for Phase 1) formed part of a larger group of people, some of whom practised fishing and shellfishing. The populations buried at El Panel, Ferrocarril, Villa el Salvador, and Lomo de Corvina show evidence for the acquisition of marine goods. This would suggest that Rostworowski's (1970, 1977a, 1977b) proposed economic arrangement for the Peruvian coast at the time of Spanish contact may apply as far back as the EIP to some coastal populations. However, Murra's (1972 in Murra, 1975) ecological complementarity scenario and other economic patterns cannot be excluded at this stage.

Results also show the necessity to establish a further isotopic baseline and isoscape for the region, specifically for $\delta^{34}S$. They illustrate the importance of sampling selection, particularly when trying to combine the type of bone with individual biological information. Perspectives for future studies are to enlarge the sample size, including enamel in the analyses, and to focus on material with more available biological criteria for comparison (*i.e.*, a very large selection of individuals but only from Phase 1).

Acknowledgements

The authors would like to thank Iso-Analytical Ltd. (Crewe, UK), J. Ughetto and M. Balasse (SSIMM MNHN UMR 7209, Paris, France) for their availability and services, A. Mazuy and M. Regert (CEPAM UMR 7264, Nice, France) for the FTIR assistance, M. Lebon and I. Reiche for their advice, the staff and students of Pachacámac Valley Program (before Lomas de Lurín), Pontificia Universidad Católica del Perú for their help and support, and the Museo Nacional de Arqueología, Antropología e Historia del Perú (Pueblo Libre, Lima, Peru) as well as the Ministerio de Cultura (Lima, Peru) for the research and export permit. We would also like to thank the anonymous reviewers for their helpful and insightful comments, as well as Mark Villeneuve for proof reading the final draft. This work was funded by a CNRS-PEPS INEE 2012 grant, by Asociación Atocongo, and by Santander International Travel Grants (Bournemouth University). Samples were exported from Peru and analysed under permit no. 057-DGPC-VMPCIC-MC (Resolución Directorial del Ministerio de Cultura, Peru).

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