

STABLE ISOTOPE SOURCING OF WOOL FROM TEXTILES AT PACATNAMÚ*

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Stable carbon and nitrogen isotopic compositions were determined for wool textiles from the Lambayeque (c. AD 1100–1320) occupation at Pacatnamú in the Jequetepeque Valley, northern Peru. The isotopic data demonstrate that the wool was not obtained via long-distance exchange with the highlands and was most probably derived from locally raised camelids. In light of other lines of evidence (diversity of dyes used to produce the same colours in textiles and the low quality of the weaving), textiles at Pacatnamú appear not to have been as effective a marker of political power and prestige for local elites as they were elsewhere in the Andean region.

KEYWORDS: STABLE ISOTOPES, WOOL, TEXTILES, PERU, CAMELIDS, TRADE, LATE INTERMEDIATE PERIOD

INTRODUCTION

The importance of textiles in the prehistoric Andes is best known from descriptions of the Inca (Late Horizon, AD 1476–1532) and numerous scholars have highlighted the predominance of textiles in economic, social, political and ritual spheres (Murra 1962, 1965, 1980; Morris 1995; Costin 1996, 2011). Although comparable records from earlier periods are lacking, it is generally agreed that textiles were of similarly great importance prior to the time of the Inca (Rowe 1980; Boytner 1998a,b, 2004; Rodman and Fernandez Lopez 2005; Millaire 2009; Surette 2015). Because of their relative rarity in most archaeological contexts at a global scale, the production, exchange and consumption of archaeological textiles have received considerably less attention relative to more durable artefacts such as ceramics, lithics and architectural elements. Nonetheless, textiles were almost certainly the most salient markers of ethnic or group identity in the Andean region (Oakland Rodman 1992; Boytner 1998b; Millaire 2009; Surette 2015), and in some cases were inextricably woven into the fabric of the political economy, serving as a foundation for imperial expansion and consolidation (Morris 1995; Costin 2011).

The exceptionally dry environment of the Peruvian and Chilean coasts facilitates the preservation of textiles and allows for a detailed examination of many aspects of craft production and exchange. The two most common raw materials used in the manufacture of Andean textiles were cotton (*Gossypium barbadense*) and camelid (alpaca [*Vicugna pacos*] and llama [*Lama glama*]) wool (Boytner 2004). Cotton was originally domesticated on the coast and was grown principally

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there, as well as in the adjacent low-altitude habitats up to about 1000 m a.s.l. (Dillehay *et al.* 2007). Camelids, on the other hand, were domesticated in the highlands (Moore 2016) and have traditionally been associated with the high-altitude grassland habitats of the *altiplano* and *puna* (~3500–4800 m a.s.l.) (Murra 1965). Generally speaking, textiles found at coastal sites are made predominantly of cotton, with wool being comparatively rare (Boytner 1998a). This relative paucity of wool on the coast has been taken as support for the notion that wool must have been imported from the highlands because of the superior quality and quantity of camelid pasturelands (Rowe 1980; Boytner 2004). Relatively little consideration has been given to the notion of coastal wool being derived from local populations of camelids (but see Shimada and Shimada 1985; Wheeler *et al.* 1995; Szpak *et al.* 2015). The term ‘local’ is environmental in this context rather than cultural and refers to the coastal river valleys up to approximately 1000 m a.s.l., where the oceanic influence on the environment is significantly reduced (Koepcke 1954).

Shimada and Shimada (1985) summarized numerous lines of evidence, suggesting that camelids were herded in a much more diverse range of habitats, including the arid coastal river valleys. Isotopic analyses of archaeological camelid remains are consistent with localized camelid husbandry being established on the north coast of Peru by at least the Early Intermediate Period (Dufour *et al.* 2014; Szpak *et al.* 2014b, 2015) and continuing through the late Middle Horizon (Szpak *et al.* 2014b, 2016b). A paucity of relevant data make the origins of coastal camelid husbandry unclear, but it may have originated during the Early Horizon (Szpak *et al.* 2016a). The presence of coastal camelids, however, does not necessarily equate with a local supply of fine fibre for textile manufacture on the coast as alpacas, which would have produced the finest wool (Antonini 2010), are believed to have been particularly ill-suited to the coastal environment (Topic *et al.* 1987). That said, some naturally mummified llamas from the Late Intermediate Period site of Yaral (Chiribaya), located at ~1000 m a.s.l. in the lower Osmore Drainage (southern Peru), exhibited fibre as fine, or finer, than that of modern alpacas (Wheeler *et al.* 1995).

In a previous investigation of textiles from the coast of Peru, we found evidence for two distinct camelid dietary patterns reflected in the carbon and nitrogen isotopic compositions of the wool (Szpak *et al.* 2015). The first is characterized by low $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, indicating a high proportion of C_3 plants in the diet. This pattern was also observed in Late Intermediate Period Chancay textiles from the central coast of Peru and is suggestive of a highland origin for the wool, lending support to the idea that wool recovered from coastal sites was being imported (Rowe 1980; Topic *et al.* 1987). This pattern has also been recorded in camelid remains from high-altitude herding sites (DeNiro 1988; Thornton *et al.* 2011; Szpak *et al.* 2015). The second pattern is characterized by higher but much more variable carbon and nitrogen isotopic compositions. This pattern was observed in textiles from two EIP sites in the Virú Valley (Szpak *et al.* 2015) and suggests that the camelids that produced the wool originated outside of the highlands, residing predominantly on the coast or in the intermediate altitudinal zones (*yungas* or low sierra) between the coast and the highlands. Isotopic data from camelids from sites located on the north coast of Peru are similarly characterized by these variable isotopic compositions, consistent with a significant contribution of C_4 plants (~50%) to the diet (Szpak *et al.* 2014b, 2016b). A final pattern, which has not been observed in textiles, involves intensive maize foddering and has only been recorded at the Middle Horizon site of Conchopata (~2700 m a.s.l.) among some of the camelids found at the site (Finucane *et al.* 2006).

From these data, it is possible to generate a series of expectations for camelid skeletal remains or textiles in terms of two significant variables: (1) the mean contribution of C_4 plants to the diet; and (2) the amount of intra-group isotopic variability (Fig. 1). For camelids raised in high-altitude pastures, the diet should consist of a small amount of C_4 plants and a low amount of isotopic

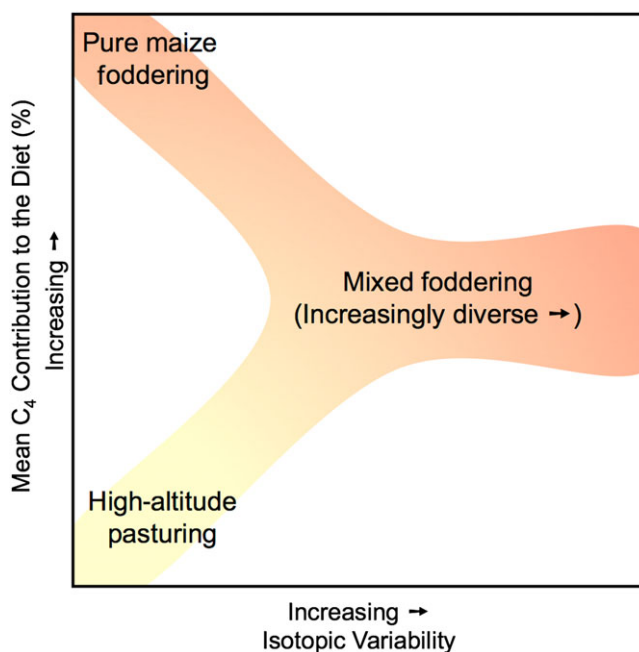


Figure 1 A bivariate plot depicting the percentage of C_4 plants in the diet (y-axis) and the amount of isotopic variability (x-axis). Shaded areas indicate theoretical ranges for groups of Andean camelids, with 'High-altitude pasturing' being indicative of a highland origin, and 'Mixed foddering' and 'Pure maize foddering' being indicative of a non-highland origin. [Colour figure can be viewed at wileyonlinelibrary.com]

variation among individuals ('High-altitude pasturing' in Fig. 1). On the basis of isotopic data collected from animals believed to have been raised on the coast or foddered at more urbanized sites outside of the highlands, a diet consisting of approximately 50% C_4 plants is expected ('Mixed foddering' in Fig. 1). For this group, the amount of within-group isotopic variation can range from relatively little (all animals eat approximately the same range of foods in similar proportions) to extremely high (the group mean C_4 dietary contribution is approximately 50%, but individual animal diets differ strongly from one another). Finally, animals consuming an almost exclusively C_4 diet due to intensive maize foddering will have a high contribution of C_4 plants and a low amount of isotopic variation. This pattern is inconsistent with high-altitude pasturelands and has only been observed at Conchopata after a *post hoc* division of the individuals according to their $\delta^{13}C$ values as opposed to any morphological distinction. Theoretically, however, such a diet would be equally possible for some of the more agriculturally productive coastal river valleys. Therefore, the further a point falls from the bottom left of the plot in Figure 1, the less is the likelihood that the group of camelids or textiles originated in the highlands.

On the basis of the limited isotopic investigations of textiles conducted to date, it is apparent that a diversity of wool production and exchange networks existed in the Andes prior to European contact, some of which fit the expected pattern of exclusively highland wool moving to the coast (Chancay) and some of which do not (Virú) (Szpak *et al.* 2015). The purpose of this study was to use stable carbon and nitrogen isotopic analyses of wool textile fragments from the Lambayeque occupation at Pacatnamú to determine whether the camelids that produced the wool were raised locally on the coast or in the highlands. It has been assumed that the wool used to manufacture textiles at Pacatnamú was not derived from locally raised camelids (Boytner 1998a, 29), a

pattern believed to be characteristic of Late Intermediate Period wool on the north coast in general (Rowe 1984, 25–6). We therefore anticipated the isotopic results to closely resemble those obtained from Chancay textiles; we found, however, that the Pacatnamú textiles were characterized by a high contribution of C₄ plants on average and large within-group isotopic variation. On the basis of these data, the wool used to manufacture the Pacatnamú textiles was most probably derived from camelids that were raised locally in the lower Jequetepeque River Valley.

CARBON AND NITROGEN ISOTOPES

The stable carbon and nitrogen isotopic compositions of an animal's tissues reflect the average isotopic compositions of the foods consumed over the period of tissue formation (DeNiro and Epstein 1978, 1981). Wool textiles are composed of the hair of llamas and alpacas, which predominantly consists of the protein keratin. The stable carbon and nitrogen isotopic compositions of keratin are approximately 3‰ higher than those of the diet (Ambrose 2000; Sponheimer *et al.* 2003), meaning that bone collagen and hair $\delta^{15}\text{N}$ values are more or less directly comparable, while bone collagen is approximately 1.5‰ enriched in ^{13}C relative to keratin (Szpak *et al.* 2014b). The primary factors influencing the stable carbon and nitrogen isotopic compositions of herbivore tissues are the isotopic compositions of the plants that they consumed (Murphy and Bowman 2006).

Western South America is an ideal ecological setting in which to conduct isotopic research, as there is significant variability in the carbon and nitrogen isotopic compositions of terrestrial plants and soils along an altitudinal transect from the coast to the highlands, running west to east (Szpak *et al.* 2013). Plant $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are influenced by a number of environmental variables, which create this altitudinal variation in the Andes. The most significant factor with respect to plant $\delta^{13}\text{C}$ is the difference between plants that utilize C₃ and C₄ photosynthesis, with the former having $\delta^{13}\text{C}$ values on average around -26‰ and the latter around -12‰ (Bender 1968). C₄ crops are rare or absent above 2500 m a.s.l. in the Andes with the exception of maize (Boom *et al.* 2001; Szpak *et al.* 2013), which is cultivated up to an altitude of 3000–3500 m a.s.l., depending on local conditions (Lauer 1993). On the coast and in the low-altitude zones, which both receive negligible precipitation, C₄ plants are abundant, although C₃ plants are still quantitatively significant in terms of biomass and number of taxa (Szpak *et al.* 2013). Moreover, maize was an important crop in this region, as reflected in the carbon isotopic composition of human populations (Verano and DeNiro 1993; White *et al.* 2009). Other factors such as soil salinity, solar irradiance, temperature and water availability can influence C₃ plant $\delta^{13}\text{C}$ values, but when comparing factors between different ecozones in the Andes, these factors are overwhelmed by the C₃ versus C₄ distinction (Szpak *et al.* 2013).

Plant nitrogen isotopic compositions are influenced primarily by two factors: the 'openness' of the local nitrogen cycle, which is ultimately influenced by climatic factors, and their associations with mycorrhizal fungi (Szpak 2014). Nitrogen cycle openness is an important factor in influencing plant nitrogen isotopic compositions in this region. Generally speaking, in warmer, drier conditions, the nitrogen cycle tends to be more 'open', or more prone to losing nitrogen through various biogeochemical processes. Consequently, these more open systems are more prone to losing ^{14}N , increasing the ^{15}N content of the residual nitrogen in the system (Handley *et al.* 1999). In the Andean region, wild plants growing in the arid coastal areas tend to have much higher $\delta^{15}\text{N}$ values on average than those growing at higher altitudes (Szpak *et al.* 2013). The same is not true for agricultural plants, which grow in soils that are typically not water limited as a result of irrigation, and therefore possess $\delta^{15}\text{N}$ values that are not unusually high (Szpak *et al.* 2012b). Plants that form symbiotic associations with N₂-fixing bacteria (legumes) tend to

have $\delta^{15}\text{N}$ values consistently around 0‰, which is frequently lower than non-legumes growing in the same area. When soil N availability is high, however, legumes will tend to take up mineralized nitrogen from the soil as non-leguminous plants do and not have unusually low $\delta^{15}\text{N}$ values (Szpak *et al.* 2014a). Legumes (peanuts and various beans) were cultivated on the north coast of Peru (Pozorski 1979) and trees of the genus *Prosopis*, which associate with N_2 -fixing bacteria, were also economically important in some areas (Beresford-Jones *et al.* 2009). The nitrogen isotopic composition of agricultural plants can be impacted by a variety of other processes (reviewed by Szpak 2014). Fertilization with animal manure can significantly increase the $\delta^{15}\text{N}$ values of plants, by 2–4‰ for livestock manure and increasing to over 30‰ for seabird guano (Szpak *et al.* 2012a), both of which were potentially available on the north coast of Peru, although no direct evidence exists for their use in this region.

THE ARCHAEOLOGICAL CONTEXT

Pacatnamú is a large and extensively excavated site situated near the mouth of the Jequetepeque River, on the north coast of Peru (Fig. 2). There were two major periods of occupation of the site. The first is associated with Moche (AD 400–900), with lighter occupations early (Moche I) and late (Moche IV, V) and the most intensive occupation during the Middle Moche (Moche II, III) (Donnan 1997). The second major occupation is associated with the Lambayeque material culture tradition during the Late Intermediate Period (LIP, *c.* AD 1100–1320) and is the period from which the samples analysed in this study are derived. Major patterns in central Andean prehistory during the LIP are summarized by Covey (2008). On the north coast, the period follows the demise of Moche and the emergence of a number of polities, including the Lambayeque and Chimú (Shimada 2000). The subsistence economy was based primarily on intensive irrigation agriculture (maize, beans and chili peppers), with tree fruits/seeds (avocado and *Prosopis*), camelids, dogs, guinea pigs and nearshore marine animals also contributing (Cutright 2015). Covey (2008) suggests that the herding of camelids did not figure in any significant way in the political economies of north coast LIP polities, although the abundance of butchered camelid remains at Chan Chan (Pozorski 1979) and the large number of ritually sacrificed camelids at Gramalote A – Huanchaquito (Goepfert and Prieto 2016) suggest otherwise.

Although the political and ceremonial functions of Pacatnamú have been debated (Donnan and Cock 1986; Boytner 1998a), it was most probably the primary administrative and ritual centre for the Lambayeque polity ruling over at least the lower Jequetepeque Valley during the LIP, sitting atop a hierarchical settlement pattern consisting of administrative centres, elite residences, agricultural or fishing villages, and defensive outposts (Donnan and Cock 1986; Cutright 2009; Mackey 2009). The beginning of the Lambayeque occupation at Pacatnamú is dated to AD 1100 and continued uninterrupted until the conquest of the Jequetepeque Valley by the Chimú around AD 1320 (Mackey 2009). Minimal occupation occurred during subsequent periods and the site was entirely abandoned when the Spanish arrived in the valley in the mid-16th century (Donnan 1997). Based on architectural and ceramic differences, Sapp (2011) posits that the Lambayeque polity can be divided into a northern and southern polity, with Pacatnamú serving as the ritual and political centre of the latter towards the end of the occupation.

MATERIALS AND METHODS

The Pacatnamú textiles represent one of the most extensive and well-studied Andean textile assemblages recovered *in situ* from their original archaeological context (Fig. 3). Their stylistic and

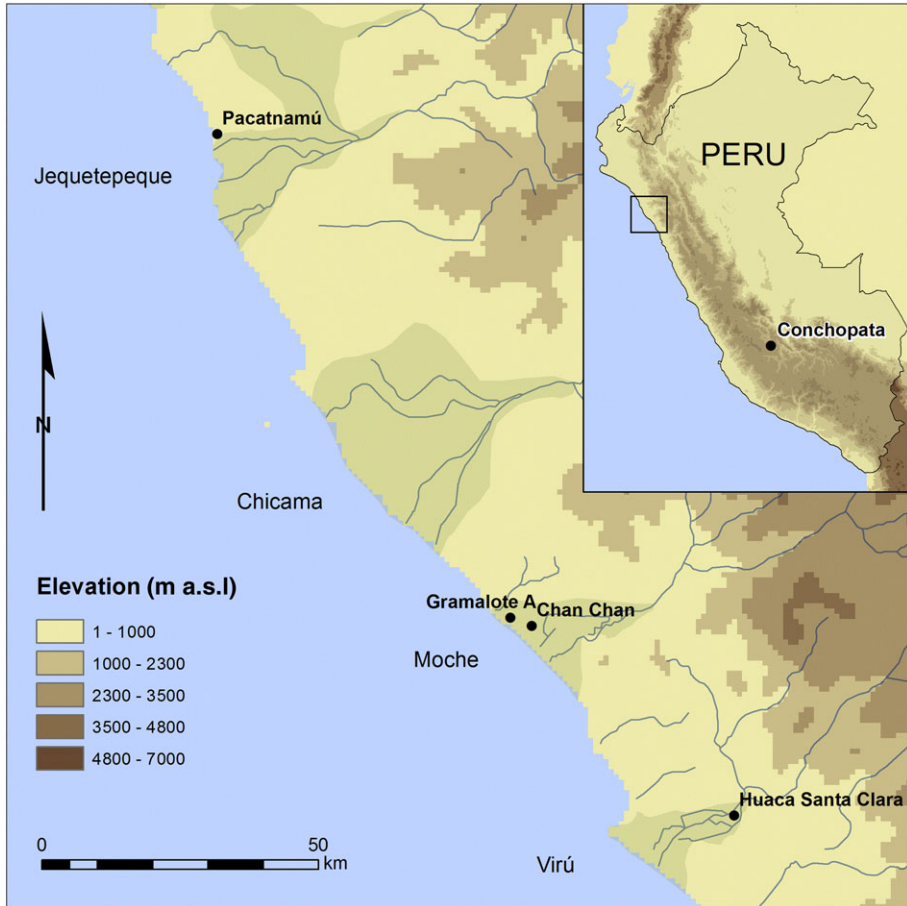


Figure 2 The locations of Pacatnamú and the river valley systems and sites mentioned in the text. [Colour figure can be viewed at wileyonlinelibrary.com]

technological elements have been described in detail elsewhere (Boyner 1998a, 2006). Textile samples were derived from the excavations of the Pacatnamú Project (1983–7), led by Donnan and Cock (1986), and are associated with the Lambayeque occupation of the site. Contextual information for each sample is provided in Table S1.

As with other coastal sites, the vast majority of the textiles recovered from Pacatnamú were made with cotton, but many also contain wool, usually in the wefts. The majority of textiles at Pacatnamú were utilitarian in nature and probably had more limited value, although this is not true of the smaller pieces; it is in these smaller pieces that the vast majority of the wool occurs (Boyner 1998a). The use of dyed camelid wool was largely limited to textiles that would have been used by elite members of the site (Boyner 2006) and the materials selected for analysis in this study therefore provide a relatively narrow view on wool production that was most probably intended for elite consumption.

Sample preparation followed Szpak *et al.* (2015). The sample consisted of 119 wool samples. Loose fibres detached from the fabric or threads hanging from damaged warps/wefts were selected for sampling in order to minimize damage. The spin direction and colour of the fibres were



Figure 3 A miniature textile from Huaca 1 at Pacatnamú (H1-F43-*Tex* 4c), 10×8.6 cm plus a 0.8 cm weft fringe on all sides (photograph by Christopher B. Donnan). [Colour figure can be viewed at wileyonlinelibrary.com]

recorded. Wool samples were first cleaned by gentle abrasion with a brush; visible foreign matter was removed using forceps. Samples were then sonicated for 15 min in Type II water to remove sediment and other particulate matter. Samples were treated with methanol for 3×15 min, followed by 2:1 chloroform:methanol for 24 h in order to remove any lipids. Samples were air dried under normal atmosphere at 90°C and then finely minced prior to being weighed into tin capsules for isotopic analysis.

Unlike collagen, there are no experimentally derived elemental markers that can be used to definitely assess whether or not archaeological keratin carbon and nitrogen isotopic compositions have been altered in the burial environment (but see von Holstein *et al.* 2014). Nevertheless, wool samples presenting atomic C:N ratios that were unusually low or high were treated as potentially degraded or contaminated, even if their isotopic compositions were not unusual.

Stable carbon and nitrogen isotopic and elemental compositions were determined using a Thermo Finnigan Delta V continuous flow mass spectrometer coupled to a Costech Elemental Analyser at the Laboratory for Stable Isotope Science (The University of Western Ontario). USGS40 and USGS41 were used for calibration of $\delta^{13}\text{C}$ relative to VPDB and $\delta^{15}\text{N}$ relative to AIR. Accuracy and precision were monitored using an internal keratin standard, IAEA-CH-6 and IAEA-N-2. Standard uncertainty was determined to be $\pm 0.15\text{‰}$ for $\delta^{13}\text{C}$ and $\pm 0.3\text{‰}$ for $\delta^{15}\text{N}$ as calculated by the method presented by Szpak *et al.* (2017) (additional details are provided in the Supplementary Methods).

The contribution of C_3 and C_4 plants to camelid diets was estimated using a single-isotope (C), two-source (C_3 , C_4) Bayesian mixing model (Parnell *et al.* 2010). Source isotopic compositions were taken from the published literature for C_3 ($-26.12 \pm 1.75\text{‰}$) and C_4 ($-12.01 \pm 0.95\text{‰}$) plants in the Moche Valley region (Szpak *et al.* 2013). The trophic enrichment factor for hair keratin ($\Delta^{13}\text{C}_{\text{keratin}}$) was estimated to be $+2.4 \pm 1.2\text{‰}$ (Szpak *et al.* 2015). The trophic enrichment

factor for bone collagen ($\delta^{13}\text{C}_{\text{collagen}}$) was estimated to be $+3.70 \pm 1.60\text{‰}$ (Szpak *et al.* 2012c). The amount of isotopic variation was quantified using the standard bivariate ellipse area as computed by the Standard Isotope Bayesian Ellipses in R (SIBER) package (Jackson *et al.* 2011). These statistical analyses were performed in R 3.3.2 for Mac OS X 10.9.5.

The stable carbon and nitrogen isotopic compositions of Pacatnamú textiles (data produced in this study) and bone collagen (Verano and DeNiro 1993) were compared using a Mann–Whitney U test. To directly compare with the two tissues, the bone collagen $\delta^{13}\text{C}$ values were adjusted by $+1.3\text{‰}$ to account for tissue-specific fractionation (Szpak *et al.* 2014b). These calculations were performed using IBM SPSS Statistics Version 23 for Mac OS X. Further comparisons were made of the amount of isotopic variability in the Pacatnamú textile and bone collagen data sets by comparing the size of the bivariate ellipses generated using a Markov Chain Monte Carlo simulation with 10^4 iterative draws in the SIBER package (Jackson *et al.* 2011). This process produces a representative sample of all the possible ellipses that can be generated given the distributions of the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, the sizes of which can then be compared. Similarly sized ellipses will produce p -values close to 0.50 (Ellipse 1 is larger than Ellipse 2 50% of the time, and therefore there is no difference in size), while very differently sized ellipses will produce p -values close to 1 (Ellipse 1 is always larger than Ellipse 2) or 0 (Ellipse 1 is always smaller than Ellipse 2).

RESULTS AND DISCUSSION

The stable carbon and nitrogen isotopic compositions of the Pacatnamú textiles are presented in Figure 4 and Table S1. These data are presented alongside bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values

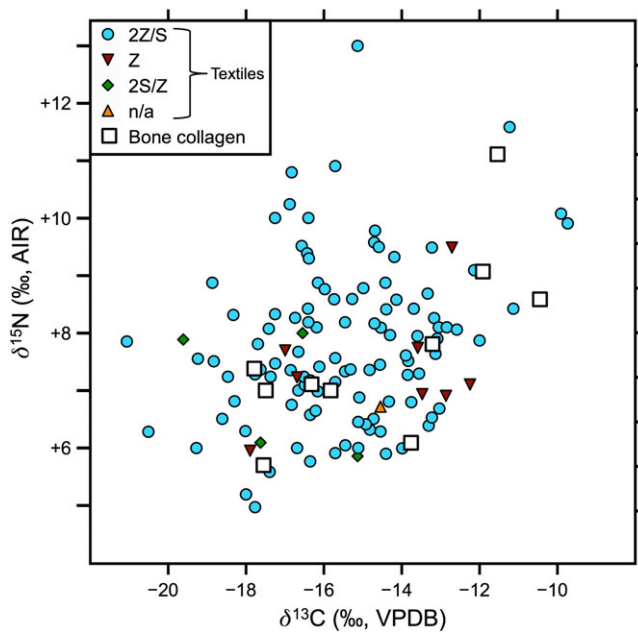


Figure 4 The carbon and nitrogen isotopic compositions of the Pacatnamú textiles and bone collagen from camelid remains from Pacatnamú (Verano and DeNiro 1993). The bone collagen $\delta^{13}\text{C}$ values have been adjusted by -1.3‰ to account for differences in tissue-specific fractionation (Szpak *et al.* 2014b). Symbols for textiles refer to different spinning styles. [Colour figure can be viewed at wileyonlinelibrary.com]

from 11 camelids from Pacatnamú previously analysed by Verano and DeNiro (1993). These camelids were derived from the Moche and Lambayeque occupations of the site, but they did not differ in their carbon or nitrogen isotopic compositions and have consequently been aggregated to create a more robust, albeit still small, sample. There were no significant differences in the carbon and nitrogen isotopic compositions between the Pacatnamú textiles and bone collagen samples (Mann–Whitney U tests: $U=578$, $p=0.55$ for $\delta^{13}\text{C}$; $U=557$, $p=0.44$ for $\delta^{15}\text{N}$). Furthermore, the amount of isotopic variation was nearly the same in the two data sets, with SEA_c being 11.8 for the Pacatnamú camelid bone collagen and 8.8 for the Pacatnamú textiles (Fig. 5). The greater size of the collagen ellipse is counterintuitive, given the much larger range of the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in the textiles—the convex hull area was 53.5 for the textiles, but only 22.7 for the collagen. Put simply, the collagen ellipse is relatively larger because there is more uncertainty due to the small sample size. Based on the comparison of the Bayesian modeled ellipses, there was no difference in the amount of isotopic variation in either group, with the textile ellipses being larger than the bone collagen ellipses in 67% of the comparisons (50% indicates exactly the same sized ellipse). Therefore, both the isotopic compositions and the isotopic variability were very similar in the Pacatnamú camelid bone collagen and textile data sets.

The vast majority of the wool samples were spun in 2Z/S (two strands of Z-spun yarns plied in S). There was no isotopic distinction between these samples and the small number that were spun in either Z or 2S/Z. For this reason, the sample was aggregated and treated as one cohesive unit. Because of the overwhelming representation of samples that were spun in 2Z/S, however, the following discussion is effectively focused on these specimens. For the entire sample ($n=119$), the

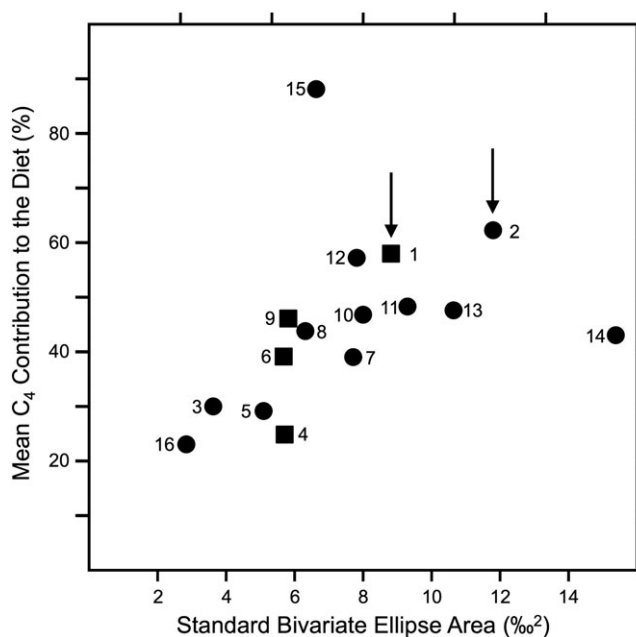


Figure 5 A bivariate plot of the standard ellipse area corrected for sample size (SEA_c ; x-axis, marker of isotopic variability) and the mean contribution of C_4 plants to the diet (y-axis) for groups of archaeological camelid bone collagen (circles) and wool (rectangles). The Pacatnamú textiles and camelid bone collagen are indicated by the arrows. Numbers correspond to specific sites as indicated in Table 1.

mean carbon and nitrogen isotopic compositions were $-15.5 \pm 2.1\text{‰}$ and $+7.7 \pm 1.4\text{‰}$, with ranges of -21.1‰ to -9.7‰ for $\delta^{13}\text{C}$ and $+4.9\text{‰}$ to $+13.0\text{‰}$ for $\delta^{15}\text{N}$.

Using a simple two-source Bayesian mixing model (Parnell *et al.* 2010), the mean contribution of C_4 plants to the diets of the camelids from which the Pacatnamú textiles were obtained was 58% (55–61%, 95% credibility interval). This amount is high compared to other camelids and wool textiles that have been analysed to date (Table 1), but is very similar to the value estimated on the basis of camelid skeletal remains from Pacatnamú (62%, 50–75%, 95% credibility interval); we recognize, however, that the Pacatnamú bone collagen data set is small, creating large uncertainty in all calculated metrics. With respect to the contribution of C_4 plants and the amount of isotopic variation, the Pacatnamú textiles are most comparable to a group of Late Intermediate Period sacrificed camelids from Huaca Santa Clara (V-67) in the Virú Valley (no. 12 in Table 1). This is particularly noteworthy as the Huaca Santa Clara sacrificed camelids provide the best evidence for camelid husbandry on the north coast of Peru (Szpak *et al.* 2014b). The very young age of these animals precluded the possibility that they were caravan animals and their varied diet and overall high contribution of C_4 plants is characteristic of the small-scale, diversified husbandry in the region. The Pacatnamú textiles are characterized by a similar degree of isotopic variation and contribution of C_4 plants as the Huaca Santa Clara camelid sacrifices (Fig. 5). On the bases of the amount of C_4 plants in the diet as well as the degree of isotopic variation, the wool used to make textiles at Pacatnamú could not have been produced from camelids raised primarily in high-altitude pastures. The fact that the amount of C_4 plants in the diet of the Pacatnamú camelids is higher than at other sites on the north coast may be driven by the greater volume of flow in the Jequetepeque River (relative to the Virú River) and the increased amount of cultivable land (Eling 1987). Together, these features would provide greater amounts of agricultural products or by-products (particularly maize) and decrease the reliance on wild fodder, particularly leguminous *Prosopis*, which is believed to have been an important camelid food source elsewhere on the coast of Peru (Shimada and Shimada 1985).

In light of the similarities between the camelid bone collagen and wool isotopic compositions at Pacatnamú and a comparison of other camelid and textile data sets analysed to date, the most parsimonious interpretation of the isotopic data is that the wool used in the Pacatnamú textiles was derived from locally raised camelids. These camelids would have been fed a wide range of foods, with a high level of variation among individuals, as has been observed at other locations on the north coast of Peru (Szpak *et al.* 2014b, 2016b).

Alternatively, it might be suggested that the highly variable carbon and nitrogen isotopic compositions of the Pacatnamú textiles reflect diverse geographical origins of the wool with respect to altitude. While this explanation cannot be conclusively ruled out, it is extremely unlikely. It would, however, require the camelid skeletal remains from Pacatnamú to have been derived from essentially the same altitudinal range as the textiles, given that the two groups are very similar isotopically. Additionally, following this reasoning, the sacrificed juvenile camelids from Huaca Santa Clara (Szpak *et al.* 2014b) would have been derived from a similarly large altitudinal range. This is an impractical if not impossible solution, given the young age of these individuals and their temporal contemporaneity. Also, if the coastal origin of the Huaca Santa Clara camelids is tenable, their isotopic similarity to the Pacatnamú textiles (Fig. 5) must be dismissed as coincidental if Pacatnamú's textiles were derived from a wide range of altitudes. We conclude that the most robust interpretation of the isotopic compositions for the Pacatnamú textiles is that the wool was derived from locally raised camelids.

This interpretation contrasts with Rowe's (1980, 1984) suggestion of the centralized production of camelid wool in the highlands and its widespread export to the coast. While previous

Table 1 The contribution of C_4 plants to the diet and standard bivariate ellipse areas corrected for sample size (SEA_c) for camelid bone collagen and wool textiles: the numbers for each site correspond to those in Figure 4

Number	Site	Period	Location	Sample type	n	SEA_c	Percentage of C_4 Mean (95% CI)	Reference
1	Pacatnamú	LIP	Coast	Textile	119	8.8	58 (55–61)	This study
2	Pacatnamú	MH/LIP	Coast	Collagen	11	11.8	62 (50–75)	Verano and DeNiro (1993)
3	Pucara	Initial Period	Highlands	Collagen	18	3.6	30 (24–36)	DeNiro (1988)
4	Chancaý*	LIP	Coast	Textile	58	5.7	25 (22–28)	Szpak <i>et al.</i> (2015)
5	Conchopata (alpaca)	Middle Horizon	Sierra	Collagen	6	5.1	29 (17–40)	Finucane <i>et al.</i> (2006)
6	Huaca Santa Clara	EIP	Coast	Textile (local production)	29	5.7	39 (35–44)	Szpak <i>et al.</i> (2015)
7	Caylán/Huambacho	Early Horizon	Coast	Collagen	19	7.7	38 (31–46)	Szpak <i>et al.</i> (2016a)
8	Huancaco	Middle Horizon	Coast	Collagen	9	6.3	44 (35–53)	Szpak <i>et al.</i> (2016b)
9	Huaca Santa Clara	EIP	Coast	Textile (foreign production)	46	5.8	46 (43–49)	Szpak <i>et al.</i> (2015)
10	Huaca Gallinazo	Early EIP	Coast	Collagen	13	8.0	47 (35–59)	Szpak <i>et al.</i> (2014b)
11	Huaca Gallinazo	Middle EIP	Coast	Collagen	43	10.6	48 (42–54)	Szpak <i>et al.</i> (2014b)
12	Huaca Santa Clara	LIP	Coast	Collagen	25	7.8	57 (50–63)	Szpak <i>et al.</i> (2014b)
13	Huaca Santa Clara	Late EIP	Coast	Collagen	43	9.3	48 (43–53)	Szpak <i>et al.</i> (2014b)
14	Cerro Baul	Middle Horizon	Sierra	Collagen	11	15.4	43 (29–57)	Thornton <i>et al.</i> (2011)
15	Conchopata (llama)	Middle Horizon	Sierra	Collagen	11	6.6	87 (80–95)	Finucane <i>et al.</i> (2006)
16	Chinchawas	Middle Horizon	Highlands	Collagen	13	2.8	23 (16–31)	Szpak <i>et al.</i> (2015)

*This sample consists of Chancaý style textiles that are likely from a variety of sites.

investigations of Chancay textiles from the central coast of Peru are consistent with Rowe's interpretation (see Szpak *et al.* 2015), the same cannot be said for Pacatnamú. Along these lines, Boytner has suggested that the notion of centralized production of wool at Pacatnamú is not consistent with the variety of dyes used (Boytner 1998a, 112–13), with single colours being produced in different textiles using several different types of dyes (Boytner 2006). The wide range of isotopic variability in the Pacatnamú wool threads similarly suggests a wide range of conditions under which camelids were raised, inconsistent with centralized or standardized production.

The probability that wool would have been acquired via long-distance trade for use in the manufacturing of elite textiles at Pacatnamú needs to be considered in light of the general economic conditions at the site during the Lambayeque occupation. On the basis of the declining quality of construction materials used at Pacatnamú towards the end of the Lambayeque occupation, McClelland (1986) posits that decreasing availability of labour directed towards construction projects may have been the cause. Similarly, the quality of the textiles at Pacatnamú is inferior to other sites, with textiles found in association with the most elite areas of the site being mediocre at best, having low thread counts, a lack of elaborate decoration and a large number of weaving mistakes (Boytner 1998a). Boytner (1998a, 142–3) interprets the poor quality of Pacatnamú's textiles as evidence for fairly harsh economic conditions during the LIP. Given this economic context, it is more likely that wool would have been acquired from locally raised camelids rather than via relatively expensive long-distance exchange. These locally raised camelids would most probably have been llamas rather than alpacas (Topic *et al.* 1987). Because the quality of modern llama wool is inferior to that of the alpaca (Antonini 2010), this locally produced fibre may have been of lower quality than that which could have been acquired from the highlands. It is important to bear in mind, however, that these distinctions between llama and alpaca fibre apply to modern breeds, and it is almost certain that prior to the massive reduction in camelid populations during the Colonial Period a wider variety of breeds existed, including llamas producing finer fibres (Wheeler *et al.* 1995). Therefore, it is entirely possible that a population of coastal llamas may have produced wool that was of superior quality compared to that of modern breeds.

The local availability of camelid wool at Pacatnamú may have directly influenced the relatively poor quality of the textiles observed by Boytner (1998a). DeMarrais *et al.* (1996, 18) point out that symbolic objects used to create or legitimize political power are regularly made from rare or exotic materials, and that elites often maintain the capacity to acquire these objects and sustain political power by controlling access to raw materials. The exotic nature of the raw materials utilized and their relative abundance are not the only factors influencing the potential of finished products to be significant markers of political power and prestige. Locally abundant materials may be fashioned into prestige goods via advanced technological processes or highly skilled labour that can be restricted and controlled by elites (Bhan *et al.* 1994). The poor quality of the Pacatnamú textiles relative to other coastal LIP weaving traditions (Rowe 1984; Asil 2015) suggests that this was not the case.

While it is difficult to directly assess the nature of camelid husbandry in the Jequetepeque Valley, given the lack of relevant data, it is possible that camelids were not only present but abundant, driven by the high agricultural productivity of the area (Eling 1987). Because our understanding of 'local' on the basis of isotopic data is strictly environmental, it does not speak to whether or not the ruling Lambayeque polity at Pacatnamú directly controlled camelid husbandry. The isotopic data only show that the camelids that produced the wool used in the Pacatnamú textiles were raised in a coastal environment. The existence of extensively cultivated

areas and a lack of productive natural pastures in the area may have necessitated a small-scale and urbanized form of camelid husbandry, with individual families or kin groups keeping small numbers of animals, as described for the Virú Valley (Szpak *et al.* 2014b). This type of camelid husbandry may have made centralized control over the local production of wool very difficult, and the capacity to utilize wool as a significant marker of prestige or political power was probably diminished, given its local abundance and lack of ‘exotic’ quality (Goldstein 2000).

SUMMARY AND CONCLUSION

Wool used in textiles at Pacatnamú during the Lambayeque occupation was not obtained from the highlands through long-distance exchange. The isotopic data are consistent with the wool being obtained from camelids that were raised on the coast. The diversity of dyes used, the relatively poor quality of the weaving and the isotopic data from the textiles all suggest that textiles were a comparatively weak marker of political power and prestige at Pacatnamú. Local elites must have relied on other mechanisms for consolidating and legitimizing their power, potentially focusing on the construction of monumental architecture and control over irrigation canals and water resources. The isotopic data obtained from the wool textiles at Pacatnamú illustrate the complexity of the production of crafts in the Andean region, contradicting the general expectation of the acquisition of wool through long-distance trade. These specific results, however, are probably not generalizable and further investigation of this sort is required to understand the production of wool across space and time.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

Table S1. Stable carbon and nitrogen isotopic compositions for all Pacatnamú textiles.

Table S2. Standard reference materials used for calibration of $\delta^{13}\text{C}$ relative to VPDB and $\delta^{15}\text{N}$ relative to AIR for the Delta V.

Table S3. Standard reference materials used to monitor internal accuracy and precision.

Table S4. Mean and standard deviation of all check and calibration standards for all analytical sessions containing data presented in this paper. Note that means for calibration standards are not presented as they are pre-determined to be equal to the known value.