BONE CHEMISTRY AT CERRO OREJA: A STABLE ISOTOPE PERSPECTIVE ON THE DEVELOPMENT OF A REGIONAL ECONOMY IN THE MOCHE VALLEY, PERU DURING THE EARLY INTERMEDIATE PERIOD

Patricia M. Lambert, Celeste Marie Gagnon, Brian R. Billman, M. Anne Katzenberg, José Carcelén, and Robert H. Tykot

In this paper we test the hypothesis that an intensification of maize production preceded the development of a regional Moche political economy in the Moche Valley of north coastal Peru during the Early Intermediate period (400 B.C.–A.D. 600). To do so we analyze stable isotopic signatures of 48 bone apatite and 17 tooth enamel samples from human remains recovered from the site of Cerro Oreja, a large urban and ceremonial center in the Moche Valley. These remains date to the Guañape, Salinar, or Gallinazo phases and provide a diachronic picture of subsistence before the appearance of the Southern Moche state. The most notable patterns identified in the study include a lack of significant change in $\delta^{13}C_{apatite}$ *values from the Guañape to Salinar phases, followed by a significant enrichment in* $\delta^{13}C_{apatite}$ *values from the Salinar to Gallinazo phases. Several lines of evidence, including archaeological context, dental data, and comparative carbon stable isotope data from experimental animal studies and studies of archaeological human remains support the interpretation that the observed* ^{13}C *enrichment in stable isotope values in the Gallinazo phase primarily reflects maize intensification. The stable isotope data from Cerro Oreja thus suggest that a shift in subsistence toward a highly productive and storable crop may have served as an important precursor to state development during the Early Intermediate period in the Moche Valley.*

En este trabajo se prueba la hipótesis de que una intensificación de la producción de maíz precedió al desarrollo de una economía política regional moche en el Valle de Moche de la costa norte del Perú durante el período Intermedio Temprano (400 a.C.–600 d.C.). Para ello se analizan firmas isotópicas estables de 48 muestras de apatita de huesos y 17 muestras de esmalte dental de los restos humanos recuperados en el sitio de Cerro Oreja, un gran centro urbano y ceremonial en el Valle de Moche. Estos restos datan de las épocas Guañape, Salinar o Gallinazo y proporcionan una visión diacrónica de la subsistencia anterior a la aparición del estado moche del sur. Los patrones más notables identificados en el estudio incluyen la falta de cambios significativos en los valores de la $\delta^{13}C_{apatita}$ *entre las épocas Guañape y Salinar, seguida por un importante enriquecimiento de los valores de* $\delta^{13}C_{apatita}$ *entre las épocas Salinar y Gallinazo. Este enriquecimiento podría haber ocurrido de tres maneras: 1) los ocupantes de la época Gallinazo Cerro Oreja podrían haber aumentado su producción de maíz; 2) estos mismos podrían haber intensificado el uso de los recursos marinos; o 3) que ellos podrían haber intensificado el uso y la producción de maíz y los recursos marinos, respectivamente. Varias líneas de evidencia apoyan la primera hipótesis, incluyendo el contexto arqueológico, los datos dentales y los datos comparativos de isótopos de carbono de los estudios experimentales con animales y la investigación de restos humanos arqueológicos que une los valores* $\delta^{13}C_{apatita}$ *similares a los observados en la muestra de la época Gallinazo con una dieta a base de maíz. Los datos de isótopos estables de Cerro Oreja por lo tanto sugieren que un cambio en la subsistencia hacia un cultivo altamente productivo y almacenable puede haber servido como un importante precursor para el desarrollo del estado durante el período Intermedio Temprano en el Valle de Moche.*

In this paper we examine the role that changes in agricultural production played in the development of a regional political economy in the Early Intermediate period (EIP; 400 B.C.–A.D. 600) in the Moche Valley of north coastal Peru. The north coast is one of several Andean regions where centralized political organizations formed in the precolumbian era. No political system on the north

Patricia M. Lambert ■ Anthropology Program, Utah State University, Logan, UT 84321 (patricia.lambert@usu.edu)
Celeste Marie Gagnon ■ Department of Anthropology, Wagner College, Staten Island, NY 10301
Brian R. Billman ■ Department of Anthropology, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599
M. Anne Katzenberg ■ Department of Archaeology, University of Calgary, Calgary, Alberta, Canada T2N 1N4
José Carcelén ■ Instituto Nacional de Cultura—La Libertad, Trujillo, Peru
Robert H. Tykot ■ Department of Anthropology, University of South Florida, Tampa, FL 33620

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coast has received more attention or been the subject of greater debate than the various Moche polities (A.D. 300–800). Although diverse in form and historical development, Moche polities were characterized by the construction of massive ceremonial centers, intricate iconographic representations of an elite religious ideology, lavish elite burials, craft specialization, and social stratification (see Bawden 1995, 1996; Billman 2010; Pillsbury 2001; Quilter and Castillo 2010).

Not surprisingly, questions related to the origins and structure of Moche political organizations, ritual practices, and elite ideology have engaged archaeologists working in this region since the work of Rafael Larco in the mid-twentieth century (Castillo 2010). Several prominent theories have been proposed to explain political change in this and other regions of Peru, including those invoking Wittfogel's (1956, 1971) hydraulic hypothesis (e.g., Haas 1987; Moseley 1974; Stanish 1994), warfare (e.g., Billman 1996; Wilson 1981, 1988), and changes in agricultural production (e.g., Billman 2002, 2010; Burger and van der Merwe 1990; Hastorf and Johannessen 1993; Kellner and Schoeninger 2008; Quilter and Stocker 1983). Those invoking agricultural change have focused on shifts in maize production, because this grain can produce high yields in certain environments; it is easily stored for long periods; and it is known to have had a prominent role in prehistoric Andean social, political, and ceremonial life (e.g., Hastorf and Johannessen 1993; Johannessen and Hastorf 1995; Kellner and Schoeninger 2008). The purpose of this study is to test the hypothesis that maize intensification played a role in the origins of a regional Moche polity in the Moche Valley, commonly referred to as the Southern Moche state.[1]

In the 1990s, Billman set out to test Wittfogel's hydraulic hypothesis of state origins in the Moche Valley, using extensive survey data from the lower and middle valleys to chart the expansion of canal systems and the rise and fall of polities from 1800 B.C. through A.D. 600 (Billman 1996, 2002). The study examined changes in the organizational requirements of the construction and maintenance of irrigation from the start of small-scale irrigation in the middle valley circa 1800 B.C. to the construction of large-scale irrigation projects on the north side of the lower valley in the Middle Moche phase. Results of the study indicated that the managerial requirements of irrigation were relatively unimportant; rather, warfare, highland-coastal interaction, and political control of irrigation systems created opportunities for leaders to form a highly centralized polity beginning around A.D. 300 (Billman 2002).

This new polity (the Southern Moche state) was profoundly different from antecedent polities in that Moche rulers exercised significant economic, military, and ideological power over the population of the Moche Valley and beyond (Billman 2010). Moche leaders based at the Huacas de Moche were able to mobilize large quantities of labor on a regular basis to construct massive monuments and irrigation canals, and to fund craft production and elaborate public rituals. The extent of labor mobilization is demonstrated by the construction of Huaca de la Luna and Huaca del Sol, which required the production of 180 million adobes over the course of perhaps 200 or 300 years (Hastings and Moseley 1975).

Billman (2010) proposed that this regional political economy was based primarily on the extraction of tribute from farming households in exchange for access to land and water. Collection of tribute in the form of staples would have required fundamental changes in the domestic economy of farmers. In addition to expansion of irrigation, farmers would have had to make changes in the types and proportions of cultigens grown, reduce crop fallowing time, and increase yields through the use of manure or guano in order to accommodate the demands of the regional political economy. In turn, these economic shifts would have resulted in changing patterns of labor, gender roles, and diet (Gagnon 2006:265–266; Gagnon and Wiesen 2011)

What role did maize play in this transformation of agricultural production? Maize played a key role in the political economy of a wide range of Andean polities, most notably the Inka empire (Bray 2009). Maize agriculture was (and still is) highly productive in coastal valleys, and the grain is readily storable and can be transported efficiently over short to intermediate distances by llamas. Further, the provisioning of fiestas, religious festivals, and work parties with *chicha de maíz* (corn beer) was considered an obligation of the Inka and Chimu empires, and by inference other earlier polities (Gagnon 2006:253; Hastorf and Johannessen 1993; Hayashida 2009; Moore 1989; Ramirez 1996; Ube-

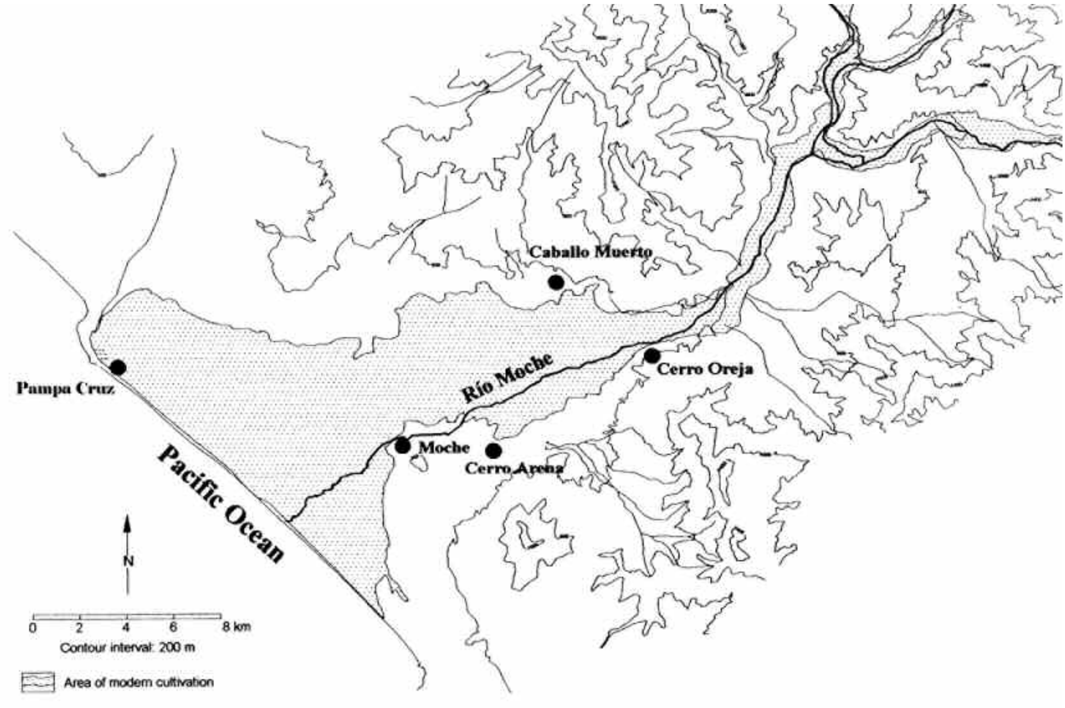

Figure 1. Map of Moche valley archaeological sites discussed in the text.

laker et al. 1995). Consequently, a shift to the intensive production of maize may have played an important role in the emergence of a regional Moche political economy based in the Moche Valley. Such a shift in maize production also might have led to changes in diet as farmers produced more maize in their fields and consumed more chicha at fiestas, religious gatherings, and work projects sponsored by rulers.

Dental health data from individuals buried at the site of Cerro Oreja (VM-710:510), a large urban and ceremonial center in the Moche Valley, provide evidence that a shift toward an increasingly cariogenic diet, such as maize would provide, occurred during the EIP (Gagnon 2006; Gagnon and Wiesen 2011). Dental caries, dental abscesses, and antemortem tooth loss have long been used as proxy measures of dietary change due to the well-documented relationship between dental disease and the consumption of refined carbohydrates (e.g., Cohen and Armelagos 1984; Hillson 1996; Kelley and Larsen 1991; Lambert 2000; Larsen 1997; Lukacs 1989; Turner 1979). At Cerro Oreja, a significant increase in the frequency of these dental indicators suggests that such a dietary shift occurred between the Salinar and Gallinazo phases (Gagnon 2006:155–166).

In this article we investigate this apparent dietary shift through the analysis of stable isotopes in human skeletal remains recovered from Cerro Oreja. The Cerro Oreja remains date to three sequential phases preceding the first construction episodes of Huaca de la Luna and Huaca del Sol in the A.D. 300s. The stable isotope data provide us with direct evidence of diet and thus can be used to examine possible shifts in political economy that pre-date the Southern Moche state.

Background

Prehistory of the Moche Valley

The primary focus of this article is the Salinar, Gallinazo, and Early Moche phases of the EIP in the Moche Valley (Figure 1). A few Guañape phase burials from the Initial period and Early horizon (1800–400 B.C.) are also included in the study and provide a glimpse into subsistence in this earlier period. The time frame represented by the human skeletal sample encompasses the period during which irrigation agriculture became established in the valley (Billman 1996, 2002).

During the Late Preceramic period (2700–1800 B.C.) a mixed economy based on marine resources and small-scale farming was established in the Moche Valley (Pozorski 1979, 1983). Marine resources exploited included mollusks, near-shore fish, and marine birds. Cultigens included gourds, cotton, squash, beans, peppers, peanuts, and several fruits, which were probably grown in small plots in sunken fields and on the floodplain of the river.

By 1800 B.C. at the start of the Guañape phase, most of the population moved from coastal settlements to the middle Moche Valley in the foothills of the Andes. People constructed small irrigation canals and presumably focused subsistence activities on agriculture rather than fishing. By the end of the Guañape phase over 4,000 ha of land was under irrigation (Billman 1996, 2002:380). In the Early Guañape phase (1800–1300 B.C.), the first mounds were constructed in the valley. Mound construction peaked in the Middle Guañape phase (1300–800 B.C.) with the construction of mounds at Caballo Muerto and several intermediate and small mounds at other sites (Billman 1996, 2002; Chauchat et al. 2006; Pozorski and Pozorski 1979; T. Pozorski 1982). Mound construction totaled more than 400,000 m^2 (Billman 1996:185, 2002). Cerro Oreja, the focus of this study, contains both Guañape phase burials and unexcavated habitations (Billman 1996) and is located across the river from Caballo Muerto and adjacent to Huaca Huatape, an intermediate-sized Guañape phase mound. The use and construction of mounds continued into the Late Guañape phase (800–400 B.C.).

At the start of the EIP in the Salinar phase (400–1 B.C.), the political landscape of the Moche Valley changed dramatically (Billman 1999). All the Guañape phase ceremonial centers, including the paramount site of Caballo Muerto, were abandoned, settlement of the lower valley expanded dramatically, the first formal fortifications were constructed and the valley's population aggregated into eight discrete site clusters (Billman 1996, 1999). Cerro Oreja was one of the few Guañape phase sites that continued to be occupied. During the Salinar phase the population of Cerro Oreja expanded, making it the second largest settlement in the valley; Cerro Arena was the largest during this time period. The eight site clusters likely were autonomous polities, although Cerro Arena was probably the dominant political power in the valley as a result of its demographic advantage over the other, smaller site clusters (Billman 1996, 1999; Brennan 1978, 1980a, 1980b; Mujica 1975). The political fragmentation of the valley, the abandonment of Guañape phase centers, and the shifts in population were probably the result of the onset of armed conflict between the coastal and highland groups, and among polities of various coastal valleys (Billman 1996, 1999, 2002). Irrigation in the Moche Valley expanded, increasing productive land to between 6,750 and 7,300 ha, a 73 percent increase over the preceding period (Billman 1996, 2002:382; Moseley and Deeds 1982). Although detailed data on food refuse are lacking for the Salinar phase, the expansion of irrigation suggests a transition from a mixed economic system anchored on the exploitation of marine protein and small-scale farming to a system of intensive agriculture (Billman 1996; Gagnon 2006:25).

In the Gallinazo phase (A.D. 1–200) the Moche Valley was unified under a single polity centered at Cerro Oreja (Billman 1996, 1999). Cerro Arena, which had a population between 5,000 and 10,000, was abandoned and the population of Cerro Oreja increased dramatically, making it the largest settlement in the valley. At its peak, perhaps more than 7,000 people lived at the site. Densely packed residences extended for 2 km along the lower slopes of Cerro Oreja. Up valley from Cerro Oreja, the population was concentrated at a series of fortified hilltop towns, which were linked visually. On the coast at Huanchaco, Pampa Cruz grew into a large fishing community, second in population only to Cerro Oreja (Billman 1996:239–242).

Leaders of the Cerro Oreja polity apparently controlled more labor than the smaller Salinar phase polities of the Moche Valley. Investment in public architecture grew from 15,000 m^3 in the Salinar phase to over 60,000 m^3 in the Gallinazo phase (Billman 2002:390). At Cerro Oreja, a large adobe mound measuring 110 by 35 by 8.5 m clings to the steep slopes above the residential area of the site. In order to create a level area to construct the mound, a cut-and-fill terrace, measuring 35 by 110 m, was carved out of the slopes. The masonry retaining walls for this terrace were massive, standing over 6 m tall (Billman 1996:241; Brisceño et al. 2006).

This new construction project demonstrates that leaders at Cerro Oreja could mobilize large groups for extended periods for construction projects.

The concentration of the population and political power at Cerro Oreja meant the Cerro Oreja polity was well-positioned to control large tracts of highly productive, irrigated land. Due to the topography of the Moche Valley, the canal intakes that water most of the broad alluvial fan of the lower valley originate at or just above Cerro Oreja. If one controls these intakes, one controls over 80 percent of the cultivable land in the lower valley. While the irrigation system did not expand significantly (Billman 2002:383), the choice of Cerro Oreja as the Gallinazo phase center is strong evidence that control of agricultural resources was essential to the power structure of the Cerro Oreja polity. The lack of major canal expansion may indicate that agricultural production stabilized during this phase, but it is equally plausible that food production was intensified through shifts in crops produced (Gagnon 2006; Gagnon and Wiesen 2011), the use of guano or manure, decreases in the length of fallowing, and the development of new and more productive varieties of cultigens, especially maize (see Bird and Bird 1980).

By the end of the Early Moche phase (A.D. 200–300), a new political and ceremonial center was founded at Huacas de Moche (Bawden 1996; Billman 1996, 2010; Moseley 1975; Topic 1977, 1982; Uceda 2001; Uceda et al. 1994). Cerro Oreja continued to be occupied, although the population may have declined. At Huacas de Moche the construction of Huaca de la Luna and Huaca del Sol was started (Uceda 2001; Uceda et al. 1994). The latter monument eventually became the largest adobe structure ever constructed in the New World (Hastings and Moseley 1975). These new monuments were radically different in form and function from antecedent monuments of the Salinar and Gallinazo phases (Billman 1996, 2010). New forms of public rituals that involved human sacrifice and the burial of select individuals with unprecedented quantities of grave goods were performed at the monuments (Billman 2010; Bourget 1996, 2001; Uceda 2001; Verano 2000, 2001). Adjacent to Huaca de la Luna, craft specialists turned out vast quantities of ceramic goods for use in domestic and mortuary rituals (Bernier 2010; Uceda and Armas 1997, 1998). Beyond the Huacas de Moche, a major expansion and reorganization of settlement occurred in the valley with the construction of large numbers of new settlements and monumental centers. Three massive canals were constructed on the north side of the Moche Valley, opening several thousand hectares of irrigated land (Billman 1996, 2002, 2010; Moseley and Deeds 1982).

Collectively these transformations indicate a profound change in the relationships between rulers and the people of the valley (Billman 2010). Moche rulers were able to harness labor and collect large quantities of goods on a regular basis from commoner households, which they used to finance a broad range of political activities, including monumental construction, public rituals, craft production, land reclamation, and possibly military actions. These transformations were manifestations of the emergence of a new regional political economy in which Moche rulers exercised significant economic, military, and ideological power over the population of the Moche and adjacent valleys.

While the Moche phase is not the primary focus of this research, the origins of the Moche polity at Huacas de Moche is. The Huacas de Moche polity (aka the Southern Moche state) was the culmination of earlier political and economic developments in the Moche and adjacent valleys, though none of the preceding polities on the North Coast achieved its size or level of complexity. The dramatic expansion of the political economy in the Middle Moche phase required the mobilization of unprecedented quantities of food stuffs to support public works projects, craft specialists, elite families, and massive public gatherings at Huaca de la Luna. These activities could not have been undertaken without an equally dramatic intensification of agricultural production.

This paper examines whether or not shifts in diet related to the intensification of agricultural production in the Moche Valley occurred before the dramatic expansion of the political economy in the Middle Moche phase, or only after and in consequence of the rise of the Moche polity. To examine this question we test the following hypotheses:

H_0 *There was no significant change in the subsistence regime in the Gallinazo phase.*

H_A *An intensification of maize production in the Gallinazo phase preceded the development of a regional Moche polity in the Moche Valley.*

These hypotheses are evaluated through the analysis of stable isotopes in human bones and teeth from the Cerro Oreja cemetery.

Stable Isotopes

Stable isotope analysis is a well-established tool for reconstructing diet in archaeological contexts (e.g., Katzenberg 1989; Kellner and Schoeninger 2008; Larsen et al. 1992; Tykot 2006; Vogel and van der Merwe 1977; Walker and DeNiro 1986). Stable carbon isotopes from preserved bone collagen were first used in paleodiet studies to indicate the presence of C_4 plants such as maize in the diet of people living in temperate regions (van der Merwe and Vogel 1978; Vogel and van der Merwe 1977). In North America, where the adoption and intensification of maize agriculture is the most significant economic transition to occur in most regions prehistorically, stable carbon isotope analysis has been used extensively to examine the timing and tempo of this transition (e.g., Buikstra and Milner 1991; Katzenberg et al. 1995; Schurr and Redmond 1991; van der Merwe and Vogel 1978; Vogel and van der Merwe 1977). Stable isotopes of nitrogen are often used in conjunction with stable carbon isotopes to provide information on trophic level, as well as the use of marine foods and certain plant food groups in the diet (e.g., Katzenberg 1989; Price et al. 1985; Sealy et al. 1987; Walker and DeNiro 1986). In South America, these dietary tracers have been used to detect the introduction of maize into the diet and to assess the importance of marine resources (e.g., Burger and van der Merwe 1990; Hastorf 1985; Hastorf and DeNiro 1985; Sandness 1992; Tykot and Staller 2002).

Carbon atoms from ingested foods are stored in two sites in the human skeleton: bone collagen and carbonate. Bone collagen is a protein and, while many of the amino acids in collagen are non-essential (i.e., can be synthesized within the body), controlled feeding experiments demonstrate that collagen nonetheless reflects the protein portion of the diet to a greater degree than it reflects the total diet (Ambrose and Norr 1993; Tieszen and Fagre 1993). Carbonate is a component of hydroxyapatite, the mineral portion of bone and tooth enamel. Carbonate from bone mineral is an attractive source for stable carbon isotope measurements in regions where bone preservation is poor because collagen may be too degraded to yield reliable results (Krigbaum 2003; van der Merwe et al. 1993). Krueger and Sullivan (1984) first suggested that carbonate would better reflect the whole diet, and this was supported by controlled feeding experiments such as those cited above. Subsequently a number of paleodiet studies have made use of both sources of carbon (e.g., Harrison and Katzenberg 2003; Kellner and Schoeninger 2007; Tykot and Staller 2002; Ubelaker et al. 1995).

Both collagen and bone apatite are subject to turnover as a result of bone maintenance and repair, whereas tooth enamel is not. For this reason, the isotopic signatures of bone collagen and apatite reflect dietary averages over the last 10 to 20+ years of a person's life (Hedges et al. 2007), whereas tooth enamel provides a measure of diet during the years of enamel formation (Eerkens et al. 2011; Wright and Schwarcz 1998).

Controlled feeding studies of rats and mice (Ambrose and Norr 1993; Tieszen and Fagre 1993) indicate that collagen is enriched in the heavier isotope of carbon (^{13}C) relative to the diet by approximately 5‰, although this number may vary depending on the specific diet and on the size of the animal (Table 1). Experimental studies further suggest that the $\delta^{13}C$ value of carbonate in the apatite of bone mineral (hereafter referred to as $\delta^{13}C_{apatite}$) better reflects the $\delta^{13}C$ of bulk carbon in the diet, but with a greater enrichment relative to whole diet on the order of about 9‰ in rodent models. However, both of these numbers can vary and neither has been experimentally determined in humans. Research on archaeological remains suggests that $\delta^{13}C_{apatite}$ enrichment in humans may be more on the order of 12‰ (Harrison and Katzenberg 2003; Tykot et al. 2009), the figure used in this study to estimate $\delta^{13}C_{diet}$ from $\delta^{13}C_{apatite}$ values. All terrestrial plants and the animals that consume them initially obtain their carbon from atmospheric CO_2. Due to deforestation and the widespread burning of fossil fuels, which are depleted in the heavier isotope of carbon, the $\delta^{13}C$ of atmospheric CO_2 has been decreasing and is now approximately 1.5‰ lower than it was prior to the industrial revolution (Boutton 1991). This number must be therefore subtracted from $\delta^{13}C$ values derived from prehistoric remains when making comparisons with values obtained from modern samples.

The difference between $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ values in a sample can provide important

Table 1. $\delta^{13}C$ Values and Diet in Experimental Animal Studies (Based on Kellner and Schoeninger 2007:1113). Sorted in Descending Order by $\delta^{13}C_{diet}$ Values.

Sample	Diet: [a]Protein/energy	% Marine In Diet	% C_4 Foods in Diet	$\delta^{13}C$ Diet	$\delta^{13}C$ Apatite	$\delta^{13}C$ Collagen	$\Delta^{13}C_{CA-CO}$ ‰
			Diets emphasizing C_3 foods				
Pig-11% Protein Diet[b]	C-C_3/C_3	0	0	-25.7	-13.6	-19.6	6.0
Mouse[c]	P-C_3/C_3	0	0	-25.6	-16.8	-21.9	5.1
Rat[d]	C-C_3/C_3	0	0	-25.2	-15.7	-21.4	5.7
Rat-20% Protein Diet[e]	C-C_3/C_3	0	0	-24.9	-14.5	-19.9	5.4
Rat-5% Protein Diet[d]	C-C_4/C_3	0	5.0	-24.3	-13.4	-14.7	1.3
Rat-20% Protein Diet[e]	MF/C_3	20.0	0	-23.3	-13.4	-14.5	1.1
Rat-70% Protein Diet[d]	C-C_3/C_4	0	~30.0	-22.5	-13.5	-20.7	7.2
Rat-20% Protein Diet[e]	C_4/C_3	20.0	20.0	-22.3	-13.0	-12.3	.7
			Diets emphasizing C_4 foods and mixed C_3/C_4 energy foods with marine protein				
Pig-13% Protein Diet[b]	C-C_3/C_3 &C_4	0	30.4	-20.5	-11.8	-18.7	6.9
Rat-20% Protein Diet[e]	MF/C_3 &C_4	20.0	35.4	-18.3	-8.6	-12.2	4.6
Pig-14% Protein Diet[b]	C-C_3/C_3 &C_4	0	50.0	-18.0	-9.0	-16.9	7.9
Rat-70% Protein Diet[d]	C-C_4/C_3	0	70.0	-17.1	-7.7	-9.7	2.0
Pig-15% Protein Diet[b]	C_3/C_3 & C_4	0	69.2	-15.9	-6.3	-15.4	9.1
Pig-23% Protein Diet[b]	MF/C_4	23.0	74.1	-15.5	-4.3	-11.5	7.2
Rat-20% Protein Diet[e]	MF/C_4	20.0	70.7	-12.9	-3.5	-9.7	6.2
Rat-20% Protein Diet[e]	C-C_4/C_4	0	90.7	-12.2	-3.1	-7.9	4.8
Rat-5% Protein Diet[d]	C-C_3/C_4	0	~95.0	-12.1	-2.9	-13.7	11.8
Mouse[c]	P-C_4/C_4	0	100.0	-11.8	-3.1	-9.8	6.7

[a]Protein source: C = casein, P = plant, MF = marine fish.
[b]Howland et al. 2003.
[c]Tieszen and Fagre 1993.
[d]Ambrose and Norr 1993.
[e]Jim et al. 2004.

insights into sources of protein and other macronutrients (e.g., carbohydrates) in the diet, particularly when these vary in $\delta^{13}C$ values (Katzenberg et al. 2009; Kellner and Schoeninger 2007; Knudson et al. 2007; Tomczak 2003). While $\delta^{13}C_{apatite}$ values are always higher than $\delta^{13}C_{collagen}$ values, the spacing between them ($\Delta^{13}C_{CA-CO}$) is variable (Ambrose and Norr 1993; Harrison and Katzenberg 2003; Kellner and Schoeninger 2007:1113), depending on and thus indicative of the various macronutrients in the diet.

In the absence of $\delta^{13}C$ and $\delta^{15}N$ values from collagen, $\delta^{13}C_{apatite}$ values alone can be challenging to interpret in maritime environments. This is because $\delta^{13}C_{apatite}$ values for marine food consumers overlap with those of C_4 food consumers and $\delta^{13}C$ values do not provide a measure of trophic level that can assist in differentiating these two groups of foods (Katzenberg 1993; Kellner and Schoeninger 2007; Norr 1995). Experimental animal studies provide one mechanism for interpreting $\delta^{13}C_{apatite}$ values in terms of the relative contribution of C_3 foods (most plants and the animals that consume them) versus C_4 foods or marine foods, or both (Ambrose and Norr 1993; Howland et al. 2003; Jim et al. 2004; Kellner and Schoeninger 2007:1113; Tieszen and Fagre 1993). Stable isotope data from archaeological human skeletal samples where dietary composition is known, or where archaeological evidence of food remains and food processing implements have been recovered (e.g., Hastorf and Johannessen 1993), can also facilitate the interpretation of carbon isotope data in these cases. All approaches are used in this study as a basis for reconstructing diet at Cerro Oreja.

Stable Isotope Research in the Andean Region of South America

In the Andean region, stable isotope analysis has been successfully employed for over 20 years in the study of paleodiet (e.g., Burger and van der Merwe 1990; DeNiro 1988; Finucane 2007; Finucane et al. 2006; Hastorf and Johannessen 1993; Kellner and Schoeninger 2008; Knudson et al. 2007; Sandness 1992; Slovak and Paytan 2011; Tomczak 2003; Tykot 2006; Tykot et al. 2008). A number of these studies have used stable isotopes to examine the role of maize in the structuring, function and/or evolution of political economies. In one of the earliest, Burger and van der Merwe (1990) used stable carbon isotopes from human bone collagen to investigate the role of maize agriculture in the origins of the Chavín civilization in the central Andean region (ca. 850 B.C.). Contrary to their expectations, they found only a slight change in maize use during the growth and efflorescence of this civilization. Maize intensification does appear to have played a role in the development of social hierarchy in the northern highlands of Ecuador, ca. A.D. 100–450 (Ubelaker et al. 1995), where high-status individuals were found to have consumed and controlled greater quantities of maize in the form of *chicha de maíz*. Imperial influence on food production was also identified isotopically by Hastorf and Johannessen (1993) in the Montaro Valley of the central Andes, ca. A.D. 500–1500. Their stable isotope data indicate that maize consumption increased from 40 to 60 percent of the diet after the Inka conquest, when *chicha de maíz* was appropriated as a state food to manage labor and build political ties. Kellner and Schoeninger (2008) tested a similar hypothesis in the Nasca region of southern Peru for the period A.D. 1–1000, but in this case found no evidence that the Wari polity intensified maize production for imperial needs.

Two studies of particular relevance to this investigation used stable carbon and nitrogen isotope ratios from bone collagen and apatite to explore diet and socioeconomic relationships within and among communities in coastal Peru (Slovak and Paytan 2011; Tomczak 2003). At Ancón on the central coast, Slovak and Paytan (2011) used this approach to clarify the nature of dietary practices during the Middle Horizon (A.D. 550–1000) and to assess how these may have changed due to Wari imperial influence. On the south coast, Tomczak (2003) explored dietary variation among Late Intermediate (A.D. 1000–1450) Chiribaya peoples of the Osmore Valley with respect to two models of resource use in order to address questions about the regional economy and political structure of the Chiribaya culture. These studies are particularly useful for this analysis because they provide very refined stable isotope models of maize use in coastal communities of Peru and they demonstrate the power of stable isotopes to reveal dietary practices not otherwise evident in the archaeological record. These studies provide a highly nuanced comparative framework for interpreting stable isotope results from Cerro Oreja.

Materials and Methods

Cerro Oreja was first investigated through limited test excavation and surface mapping by members of the Chan Chan-Moche Valley Project (Moseley and Deeds 1982). In 1994 and 1995, José Carcelén directed salvage excavations at Cerro Oreja for the Instituto Nacional de Cultura–La Libertad in order to mitigate the effects of the construction of the Chavimochic Canal. Although much of the site was outside the area of impact, most of a large cemetery was excavated (Carcelén 1995) and represents one of the largest, unlooted burial samples in Peru. Jesús Briceño and Brian Billman (Briceño et al. 2006) followed this work with comprehensive total station mapping of all visible architecture and systematic surface of collection of two-thirds of the site.

An inventory of burials and grave offerings indicates that the 909 burials from this cemetery date from the Initial period through the Early Moche phase of the EIP (Carcelén 1995:114–146[2]), although the cemetery may not have been in continuous use over these years. Most ($n = 816$) of the burials date to the Gallinazo phase, but the sample also includes seven Guañape, 78 Salinar, six Early Moche and two possible Chimu burials (Table 2).

The cemetery has a complex depositional history (Carcelén 1995:18–20, 32–38). During the Guañape and Salinar phases, and early in the Gallinazo phase, the deceased were placed in subterranean graves, sometimes accompanied by ceramic grave goods. During the Gallinazo phase, the cemetery was covered by aeolian deposits. On top of this new surface a series of masonry chambers were constructed, in which people were buried. Later, these mortuary structures were filled and the cemetery was again capped. Late in the Gallinazo phase people were again buried in subterranean pits excavated into this new surface.

Table 2. Temporal Affiliation of Burials in the Cerro Oreja Sample.

Time Phase		No. Burials[a]	% Total Burials by Sub-Phase	% Total Burials by Phase	Burials with Ceramics n	Burials with Ceramics %
Guañape		7	-	.8	7	100.0
Salinar		78	-	8.6	55	70.5
Gallinazo	Pre-Structural	302	33.2	89.7	170	20.8
	Structural	323	35.5			
	Recuay	3	.3			
	Post-Structural	139	15.3			
	Gallinazo Unidentified	49	5.4			
Moche		6	-	.7	6	100.0
Chimu(?)		2	-	.2	0	0
Total		909	89.7	100.0	238	26.2

[a]Counts are based on Carcelén (1995:132–156, Anexo No.2, Catalogo No. 3 and Inventario No. 2).

The dating of graves by Carcelén (1995:34–36) was based primarily on stratigraphy and the inclusion of ceramic vessels identified as Cupisniqiue (Guañape), Salinar, Recuay, Castillo, Gallinazo Negative, or Moche I. Using site stratigraphy Gallinazo phase interments were further divided into three sub-phases termed from earliest to most recent: Pre-Structural—interments predating the first capping of the cemetery; Structural—interments within mortuary structures; and Post-Structural—interments postdating the second capping. In addition to the changes in grave type seen during this time, Gallinazo phase mortuary practices involving the use of ceramics at Cerro Oreja appear to have varied greatly from those that characterized earlier and later phases (Billman 2010; Donnan and Mackey 1978; Millaire 2002; Tello et al. 2003). Of the graves dating to the Guañape and Salinar phases, 100 percent and 71 percent respectively contained ceramic grave offerings (Table 2). During the Gallinazo phase this percentage fell to 21 percent. In all phases most vessels were plainware domestic forms (Carcelén 1995:132–156).

Three radiocarbon dates obtained on human bone collagen from Cerro Oreja burials help to date the Cerro Oreja cemetery sample (Table 3). The calibrated (2σ) range for the single Salinar sample is B.C. 418–345, although a somewhat later date of 329–205 B.C. is indicated if the diet contained a hypothetical 10 percent marine protein. The calibrated (2σ) ranges for two samples from the Structural Gallinazo phase are B.C. 180–A.D. 73 and B.C. 64–A.D. 93. When corrected for a hypothetical marine dietary component of 10 percent, the 2σ range for these dates is B.C. 115–A.D. 127 and B.C. 45–A.D. 169 respectively. Given that the two Gallinazo samples derive from the middle subphase of the Gallinazo phase occupation at Cerro Oreja, either estimate produces bracketing dates for the Gallinazo occupation at Cerro Oreja of about 50 B.C.–A.D. 120.

Of the total 909 burials excavated from Cerro Oreja's largest cemetery, 681 have been analyzed (Gagnon 2006). As some graves contained the remains of more than one person, the total number of individuals thus far examined is 750. Preservation of the Cerro Oreja skeletal collection ranged from good to poor, but much of it was poorly preserved—especially the Post-Structural Gallinazo stratum of burials. As a result most skeletal elements required extensive reconstruction before basic data could be collected. Teeth were similarly affected, and in many cases had to be reconstructed from tooth enamel fragments. In order to maximize the data collected, those individuals characterized as having good to fair preservation were preferentially examined (Gagnon 2006:69–70). When choosing individuals for the stable isotopic analysis, efforts were made to sample all time periods and sections of the cemetery to provide broad representation within and across temporal samples (Figure 2). Both males and females, and individuals of varying ages were included in the sample. However, as bone quality can affect stable isotopic analysis, the sampling strategy was skewed toward those individuals with the best preservation, and the final stable isotopic sample therefore does not equally represent all temporal phases.

Bone collagen and carbonate from 48 human bone samples and 17 tooth enamel samples of 51 individuals were analyzed for stable carbon and nitrogen isotopes (Table 4). In order to prevent fur-

Table 3. Radiocarbon Dates on Human Bone from Cerro Oreja.

Assigned Phase	Burial	Conventional RC Age[a]	Calibrated Age SH Range–2 sigma[b]	*p* dist	Mixed marine	Ceramic Associations
Salinar	839	2360 ± 40 BP	B.C. 418–345[c]	.574	0	Red ware bowl, undecorated
		(Beta-152614)	B.C. 322–205	.383		Short-necked burnished red ware jar
			med. prob. BC 382 ± 37			with horizontally segmented upper body
			B.C. 398–336	.367	10%	
			B.C. 329–205[3]	.633		
			med. prob. B.C. 267 ± 62			
Gallinazo	125	2040 ± 40 BP	B.C. 64–A.D. 93	.924	0	Two bird effigy spout & bridge bottles with
Structural		(Beta-152612)	***med. prob. A.D. 14 ± 79***			band of negative painted wavy lines on body
			B.C. 45–A.D. 169	.995	10%	Stirrup & spout bottle with globular body
			med. prob. A.D. 61 ± 107			Bird effigy double-chambered whistling bottle
						Short-necked pitcher with globular body,
						flared neck & incised geometric design on collar
Gallinazo	425	2090 ± 50 BP	BC 180–AD 73	1.00	0	None
Structural		(Beta-164521)	***med. prob. B.C. 45 ± 127***			
			B.C. 115–A.D. 127	.995	10%	
			med. prob. A.D. 6 ± 121			

Note: Calibrations based on southern hemisphere atmospheric curves and mixed SH atmospheric/marine curves at 10 percent marine.
[a]Beta Analytic AMS Facility: dates corrected for isotopic fractionation.
[b]Calib 6.0 Radiocarbon Calibration for Southern Hemisphere. Marine Reservoir Effect for the Moche River Mouth coastal region: Delta R = 165 ± 49 years. Median probability calculated on complete *p* distribution (Reimer et al. 2009; Stuiver & Reimer 2010).
[c]Value used in estimating mean date.

ther destruction of the collection and maintain its analytical value, isotopic samples were taken from previously fragmented ribs, long bones, and teeth; thus no complete elements were destroyed in this analysis. Due to the poor preservation of teeth and their value for many types of analyses, any that were whole or could be reconstructed were preserved and only the remaining fragments of unidentified permanent teeth were sampled for isotopic analysis. Dental enamel values in this study thus

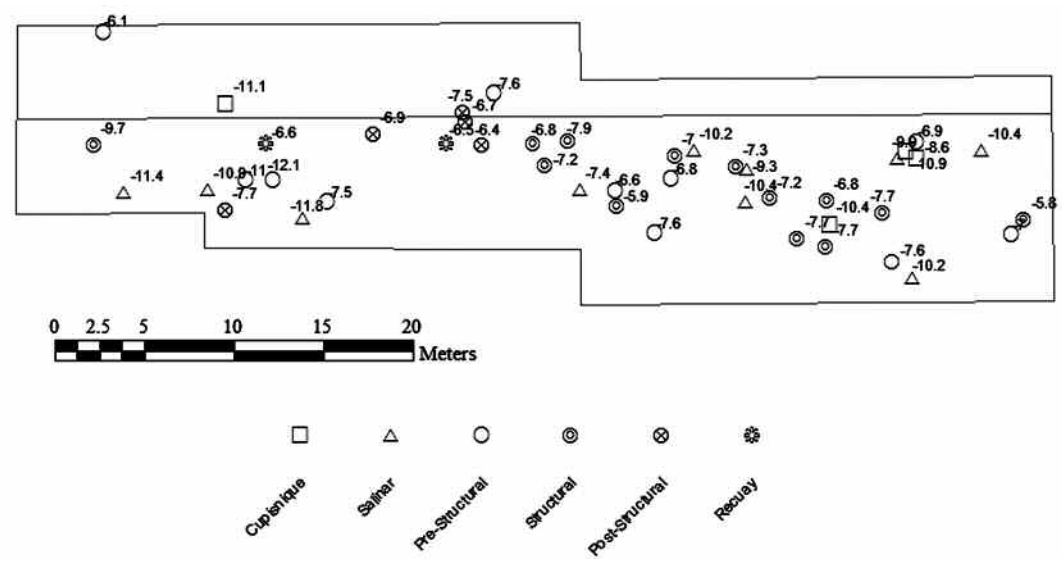

Figure 2. Distribution of burials sampled for stable isotope analysis by phase. Several individuals included in the stable isotope study were not included on field maps and are not indicated here.

Table 4. Carbonate $\delta^{13}C$ Values for Cerro Oreja Human Bones Samples by Phase. Samples Sorted in Descending Order by $\delta^{13}C_{apatite}$ Values.

Phase	Study Phase	Burial	Age (Yrs)	Sex	Bone Apatite $\delta^{13}C$ values	Tooth Enamel $\delta^{13}C$ values
Guañape	II	651	35±10	M	-11.1	-11.4
	I	869	31±5	F	-10.9	-
	II	880	56±10	F	-10.4	-11.8
	II	865	>30	F	-8.6	-12.2
				Mean Guañape $\delta^{13}C$	-10.3	-11.8
				Mean Guañape $\delta^{13}C_{diet}$	-22.3	
Salinar	II	660	33±5	M	-	-11.8
	II	362	32±5	M	-11.4	-
	I	739	19±3	M	-10.9	-
	II	837	37±5	F	-10.4	-10.1
	I	858	17±3	F	-10.4	-
	II	890	45±10	F	-10.2	-
	II	897	21±3	M	-	-10.2
	II	861	30±5	F	-9.9	-
	I	859	45±10	M	-9.3	
	II	745	35±8	?	-7.4	-6.4
				Mean Salinar $\delta^{13}C$	-10.0	-9.6
				Mean Salinar $\delta^{13}C_{diet}$	-22.0	
Gallinazo Pre-Structural	II	573	28±5	F	-	-12.1
	I	484	28±5	F	-11.0	-
	II	758	19±2	M	-7.6	-8.7
	I	320	13±2	M	-7.6	-
	I	747	12±3	?	-7.6	-
	II	771	25±5	F	-7.6	-6.5
	II	198	48±6	F	-7.5	-
	I	613	35±7	M	-7.5	-
	II	308	39±5	F	-7.0	-
	I	807	42±5	F	-6.9	-
	II	755	40±10	M	-6.8	-
	II	690	13±2	M	-6.6	-
	II	659	24±3	?	-6.1	-5.9
				Mean Gallinazo Pre-Structural $\delta^{13}C$	-7.5	-8.3
				Mean Gallinazo Pre-Structural $\delta^{13}C_{diet}$	-19.5	
Gallinazo Structural	II	61	32±5	F	-7.9	-
	II	381	35±5	F	-9.7	-
	I	556	37±5	F	-7.9	-
	I	423	21±3	F	-7.7	-
	I	668	20±3	F	-7.7	-
	I	667	32±10	F	-7.3	-
	II	761	28±10	M	-7.3	-8.7
	II	460	40±10	F	-7.2	-
	I	483	29±5	F	-7.2	-
	II	445	36±5	M	-7.0	-
	II	118	>20	?	-6.8	-5.0
	II	770	42±7	M	-6.8	-
	I	108[a]	39±5	M	-6.5	-
	II	654	42±5	F	-5.9	-5.5
	II	273	22±5	F	-5.8	-
				Mean Gallinazo Structural $\delta^{13}C$	-7.3	-6.4
				Mean Gallinazo Structural $\delta^{13}C_{diet}$	-19.3	

Table 4 (continued). Carbonate $\delta^{13}C$ Values for Cerro Oreja Human Bones Samples by Phase. Samples Sorted in Descending Order by $\delta^{13}C_{apatite}$ Values.

Phase	Study Phase	Burial	Age (Yrs)	Sex	Bone Apatite $\delta^{13}C$ values	Tooth Enamel $\delta^{13}C$ values
Gallinazo	II	301	27±7	F	-7.9	-
Post-Structural	II	156	>30	M	-7.7	-
	II	66	18±3	F	-7.5	-
	II	199b	46±5	F	-6.9	-7.8
	II	65	27±7	F	-6.7	-5.3
	II	60	27±7	M	-6.4	-5.6
			Mean Gallinazo Post-Structural $\delta^{13}C$		-7.2	-6.2
			Mean Gallinazo Post-Structural $\delta^{13}C_{diet}$		-19.2	
Gallinazo–?	I	692	38±5	M	-11.1	-
	II	907	35±5	F	-7.1	-
	II	144	18±3	F	-6.6	-

[a]Gallinazo Recuay.

provide a general measure of diet during the period of permanent tooth crown formation: approximately six months to 12 years (White and Folkens 2005:366). The remains were analyzed in two phases. Phase I was conducted by M. Anne Katzenberg at the University of Calgary using rib samples from 16 individuals. In phase II, 32 long bone samples and 17 tooth enamel fragment samples were analyzed by Robert H. Tykot at the University of South Florida.

Methods for collagen extraction differed slightly between the two institutions. Following Sealy (1986), phase I bone was cleaned in an ultrasonic cleaner for approximately 10 minutes, then dried. Dried samples were weighed then soaked in 1 percent hydrochloric acid (HCl). Acid was changed several times until bone mineral was removed. The remaining organic material was soaked in .125 M sodium hydroxide (NaOH) overnight. Samples were then rinsed to neutrality and centrifuged, and the remaining sample was lyopholized and weighed. In phase II, bone collagen was extracted by demineralizing whole bone using a slightly more concentrated 2 percent hydrochloric acid for 72 hours, dissolving base-soluble contaminants using .1 M sodium hydroxide (24 hours before and after demineralization), and separating residual lipids with a mixture of methanol, chloroform, and water for 24 hours.

In phase I, collagen yields were found to be very low (between .8 and .2 percent) and eight samples yielded no collagen. Samples were analyzed for stable isotopes of carbon and nitrogen on a Finnigan MAT Delta + mass spectrometer interfaced with a Carlo Erba gas analyzer in the Isotope Science Laboratory, University of Calgary. Given the low collagen yields, there was insufficient sample to measure nitrogen and therefore no data on stable isotopes of nitrogen. Thus, there are no C/N data for evaluating the quality of the small amount of collagen that was recovered. Data on %C range from 17 percent to 4 percent, much lower than the expected 30–44 percent found in well-preserved bone. Collagen yields in the phase II study were similarly insufficient for stable isotope analysis.

Since the stable carbon isotope data from collagen were severely limited and those obtained potentially affected by diagenesis, carbonate was isolated from bone mineral and tooth enamel. In phase I, approximately .5 grams of whole bone was ground in a mortar and pestle. Bone powder was treated with 2 percent sodium hypochlorite (NaOCl) following the method of Lee-Thorp (1989). After five rinses, the samples were soaked in dilute acetic acid (.1M). After two hours, samples were rinsed under vacuum then freeze-dried. Samples were analyzed in Erlangen, Germany under the direction of Dr. Michael Joachimski. The carbonate powders were reacted with 100 percent phosphoric acid (density > 1.9) (Wachter and Hayes 1985) at 75°C using a Kiel III online carbonate preparation line connected to a ThermoFinnigan 252 mass spectrometer. Results are reported in per mil relative to V-PDB. Reproducibility of replicate analyses of laboratory standards is better than ± .03‰. In phase II, apatite and enamel carbonate samples were similarly extracted using established techniques, with removal of organic components using sodium hypochlorite (24 hours for enamel, 72 hours for apatite), and of non-biogenic carbonates using buffered 1 M acetic acid (24 hours). Apatite and enamel samples were analyzed with a Finnigan MAT Delta Plus instrument using a Kiel III device with 100 percent phosphoric acid at 90° C (Tykot 2006).

Several types of analyses were conducted to test for diagenetic effects that could have altered $\delta^{13}C$ signatures in the bone and tooth samples. Fourier transform infrared spectroscopy (FTIR) scans were carried out on phase I bone samples prepared for carbonate analysis. Crystallinity indices range between 3.95 and 2.74 and there is no correlation (Pearson's $r = .129$) between the crystallinity indices and the bone carbonate $\delta^{13}C$. Both the indices (< 4.0) and the lack of a correlation suggest that the $\delta^{13}C$ data from bone carbonate are providing dietary information. Although FTIR does not provide an infallible measure of diagenesis, it does offer a reasonable measure of increased crystallinity due to chemical alteration in the burial environment. Our data do not show evidence of increased crystallinity.

The $\delta^{18}O$ values obtained in both phases of the analysis were also used to test for possible diagenetic effects on bone mineral. Although oxygen isotopes are thought to be more subject to diagenesis than stable carbon isotopes in bone, Wright and Schwarz (1996) have shown that oxygen isotope ratios may be helpful in detecting bone that has been altered in the burial environment. Pretreatment methods, as developed by Lee-Thorp (1989) and modified by others (e.g., Garvie-Lok et al. 2003), serve to eliminate adsorbed carbonate and organic matter. If some adsorbed carbonate remains, there will be enrichment of both ^{13}C and ^{18}O, the heavier isotopes. If organic matter remains, there will be depletion of the heavier isotopes of both carbon and oxygen. Neither tooth enamel nor bone apatite shows a significant correlation between $\delta^{13}C$ and $\delta^{18}O$ values (Pearson's $r = .390$; $p = .121$; and Pearson's $r = -.095$; $p = .520$, respectively), which would be expected in the case of systematic contamination, although there is more variation in enamel $\delta^{18}O$ than in bone carbonate. These data support the assertion that the $\delta^{13}C$ values obtained in the study are providing information on diet rather than postmortem diagenesis.

Because tooth enamel is less susceptible to diagenesis than bone apatite (Lee-Thorp and Sponheimer 2003), a correlation coefficient also was calculated on matched bone apatite and enamel values from a subset of phase II individuals. A lack of correspondence of $\delta^{13}C$ values between these tissue types would provide evidence that the bone apatite samples had been subject to diagenesis. However, the results are highly correlated (Pearson's $r = .852$; $p < .001$), with a mean difference of ± 1.12‰, supporting the validity of the $\delta^{13}C_{apatite}$ isotope data obtained in phase II of the analysis. These results were extrapolated to the phase I sample through a *t*-test comparing phase I and phase II $\delta^{13}C_{apatite}$ values for the Structural Gallinazo phase (the phase with the most $\delta^{13}C_{apatite}$ values from phase I and phase II of the analysis): no significant differences were observed ($t = -.579$; df $= 13$; $p = .572$).

The apatite and enamel data were analyzed in relation to several variables in order to identify patterning in the data. These included analyses to establish the validity of the stable isotope data, as well those focused on temporal phase, age, and sex. The age and sex variables were included to permit the identification of age and gender differences in diet that could speak to questions of how maize was being consumed and for what purpose (e.g., provisioning of male labor). Carbon isotope ratios are reported in tables and charts using the delta (δ) notation per mil (‰) relative to the PDB and AIR standards respectively.

Results

As indicated above, attempts to obtain carbon and nitrogen stable isotope values from bone collagen were largely unsuccessful due to the low collagen content of the sampled bones. For this reason, the analysis focused almost exclusively on carbon isotopes of carbonate from bone apatite and tooth enamel. Two $\delta^{13}C$ values obtained on bone collagen during the AMS dating analysis provide protein signatures for Salinar and Gallinazo phases useful for a preliminary assessment of the protein component of the diet (see Table 5).

The most significant pattern identified in the stable carbon isotope data is a change in $\delta^{13}C_{apatite}$

Table 5. Comparative $\delta^{13}C$ Values and Diet for Archaeological Human Skeletal Samples. Sorted in Descending Order by $\delta^{13}C_{apatite}$ Values.

Sample	Diet: Protein/energy	$\delta^{13}C_{apatite}$	$\delta^{13}C_{collagen}$	$\Delta^{13}C_{CA\text{-}CO}$ ‰
Tierra del Fuego Inland HG[a]	C_3/C_3	-15.5	-20.5	5.0
Late Woodland Georgia[b]	C_3/C_3	-14.9	-19.4	4.5
Ontario Hunter-gatherers[c]	C_3/C_3	-13.1	-19.8	6.7
Ontario Early Maize[c]	$C_3/C_3,C_4$	-12.0	-19.0	7.0
Southwestern Cape[d]	Marine/C_3	-11.2	-13.9	2.7
Tierra del Fuego Coast HG[a]	Marine/C_3	-10.5	-13.3	2.8
Cerro Oreja Guañape[e]	?	-10.3	-	-
Cerro Oreja Salinar[e]	?	-10.0	[-20.9]	[10.9]
Cahokia High Status[f]	C_3/C_4	-9.1	-17.5	8.4
Chiribaya Coastal Valley-C Alta[g]	Marine/C_3,C_4	-9.1	-13.1	4.0
Chiribaya Coastal Valley-C Baja[g]	Marine,$C_3/C_3,C_4$	-8.8	-13.3	4.5
Chiribaya Inland-Yaral[g]	$C_3/C_4, C_3$	-8.4	-14.0	5.6
Chiribaya Coast-San Geronimo[g]	Marine/C_3	-8.3	-12.0	3.7
Cerro Oreja Gallinazo[e]	?	-7.4	[-17.3]	[9.9]
Illinois River Valley-Upland[h]	C_3/C_4	-6.8	-14.1	7.3
Ancón-Early Middle Horizon[i]	Marine,$C_4/C_4,C_3$	-6.0	-12.3	5.6
American Bottom-Upland[h]	C_3/C_4	-5.8	-12.8	7.0
Ancón-Late Middle Horizon[i]	C_4,Marine/C_4,C_3	-5.4	-12.0	5.3
Ontario Maize Farmers[c]	C_3/C_4	-5.1	-11.5	6.4
American Bottom-Floodplain[h]	C_3/C_4	-5.1	-11.1	6.0
Grasshopper Pueblo, SW[j]	C_3/C_4	-4.9	-10.0	5.1
Cahokia Low Status[f]	C_3/C_4	-4.2	-16.4	12.2

[a] Yesner et al. 2003.
[b] Tucker 2002, based on Kellner and Schoeninger 2009: Table 3.
[c] Harrison and Katzenberg 2003.
[d] Lee-Thorp et al. 1989, based on Kellner and Schoeninger 2007: Table 3.
[e] Current study. Collagen $\delta^{13}C$ values for Salinar and Gallinazo were obtained during AMS analysis. Indicated in brackets, each represents a single individual, not mean values for the sample.
[f] Ambrose et al. 2003.
[g] Tomczak 2003.
[h] Hedman et al. 2002, based on Kellner and Schoeninger 2009: Table 3.
[i] Slovak and Paytan 2011: Table 1. $\Delta^{13}C_{CA\text{-}CO}$ values based on subset of samples for which both carbonate and collagen values were available.
[j] Ezzo 1993, based on Kellner and Schoeninger 2009: Table 3.

values between pre-Gallinazo and Gallinazo phase samples (Table 4; Figure 3). The pattern is not one of gradual change, however, but rather is a marked shift in mean $\delta^{13}C_{apatite}$ values of 2.5‰ between the Salinar and Pre-Structural Gallinazo phases (t = –4.518; df = 18; $p < .001$). There are no significant differences between Guañape and Salinar $\delta^{13}C_{apatite}$ values (t = -.359; df = 10; p = .727), Pre-Structural and Structural Gallinazo $\delta^{13}C_{apatite}$ values (t = -.574; df = 25; p = .571), or Structural and Post-Structural Gallinazo $\delta^{13}C_{apatite}$ values (t = -.153; df = 19; p = .880). These data indicate that a change in diet toward ^{13}C enriched foods occurred between the Salinar and early Gallinazo phase use of the cemetery at Cerro Oreja, and suggest a hiatus in use of the cemetery between the two phases. The two $\delta^{13}C$ values obtained from the AMS dating analysis of bone collagen (Table 5) suggest a similar shift of 3.6‰ (2.7‰ for apatite values) between the Salinar and Structural Gallinazo phases.

An age-based comparison of diet produced mixed results. A correlation analysis examining the relationship between age (for individuals 12 and older) and $\delta^{13}C_{apatite}$ values in the Gallinazo phase component of the sample found no significant correlation between these two variables (Spearman's r = .163; p = .357; n = 34). People's diets during this time period do not appear to have shifted with respect to dietary ^{13}C from adolescence to old age. Although a strong positive correlation between $\delta^{13}C_{enamel}$ and $\delta^{13}C_{apatite}$ values (Pearson's r = .852; $p < .001$; n = 14 paired samples) indicates that diet

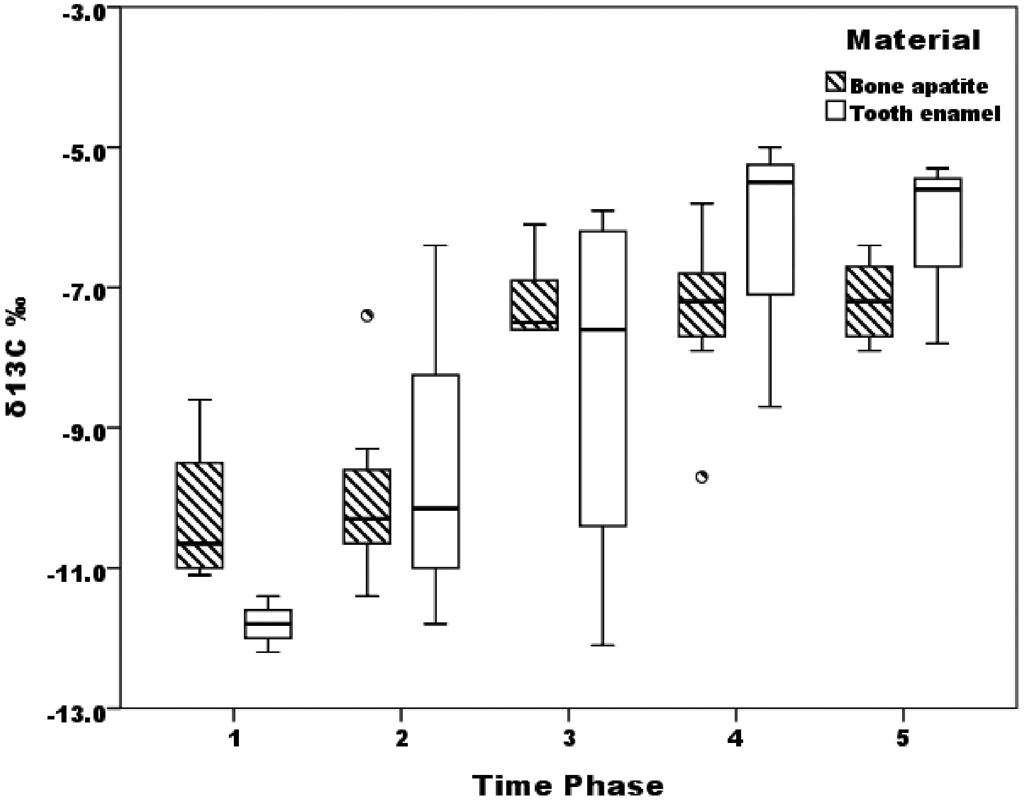

Figure 3. Boxplot of $\delta^{13}C_{apatite}$ values (for individuals 15+ years) and $\delta^{13}C_{enamel}$ values by phase. Phases: 1 = Guañape, 2 = Salinar, 3 = Pre-Structural Gallinazo, 4 = Structural Gallinazo, 5 = Post-Structural Gallinazo.

also did not differ significantly between the tooth-forming years and adulthood, a plot of adult apatite values and enamel values reveals some time sensitive and potentially meaningful age differences in diet (Figure 3). In the Guañape phase, enamel values are less enriched in the heavier isotope than adult apatite values. Enamel values in the later Gallinazo phase samples (Structural and Post-Structural), on the other hand, show the opposite pattern and tend to be more enriched in ^{13}C than adult apatite values. Salinar and Pre-Structural Gallinazo phase values overlap. Although tooth enamel values can show much greater variance than apatite values due to seasonal and annual differences reflected in incremental enamel structure (Eerkins et al. 2011; Wright and Schwarcz 1998), the $\delta^{13}C_{enamel}$ values nonetheless suggest that the diet of subadults (6 months–12 years) differed from that of adults in some phases and that the subadult diet came to be relatively more enriched in ^{13}C during the Gallinazo phase.

Figure 4 showing $\delta^{13}C_{apatite}$ values by sex reveals some differences between males and females by time period, with females having more ^{13}C enriched values in the Guañape and Salinar phases, and males having more ^{13}C enriched values during the Gallinazo phase. While this patterning is suggestive of dietary differences between males and females, these differences are not statistically significant, either for the sample as a whole (t = -.170; df = 42; p = .866), or for the Gallinazo phase (t = .159; df = 31; p = .875).

The single $\delta^{13}C$ apatite value from an individual buried with a highland Recuay vessel, obtained for a male from the Structural Gallinazo sample, is more enriched in carbon–13 ($\delta^{13}C_{apatite}$ = –6.5‰) than 80 percent of the values obtained for this phase (mean $\delta^{13}C_{apatite}$ = –7.2‰). However, this value falls within one standard deviation of the mean, suggesting that the diet of this male did not differ significantly from others of this period.

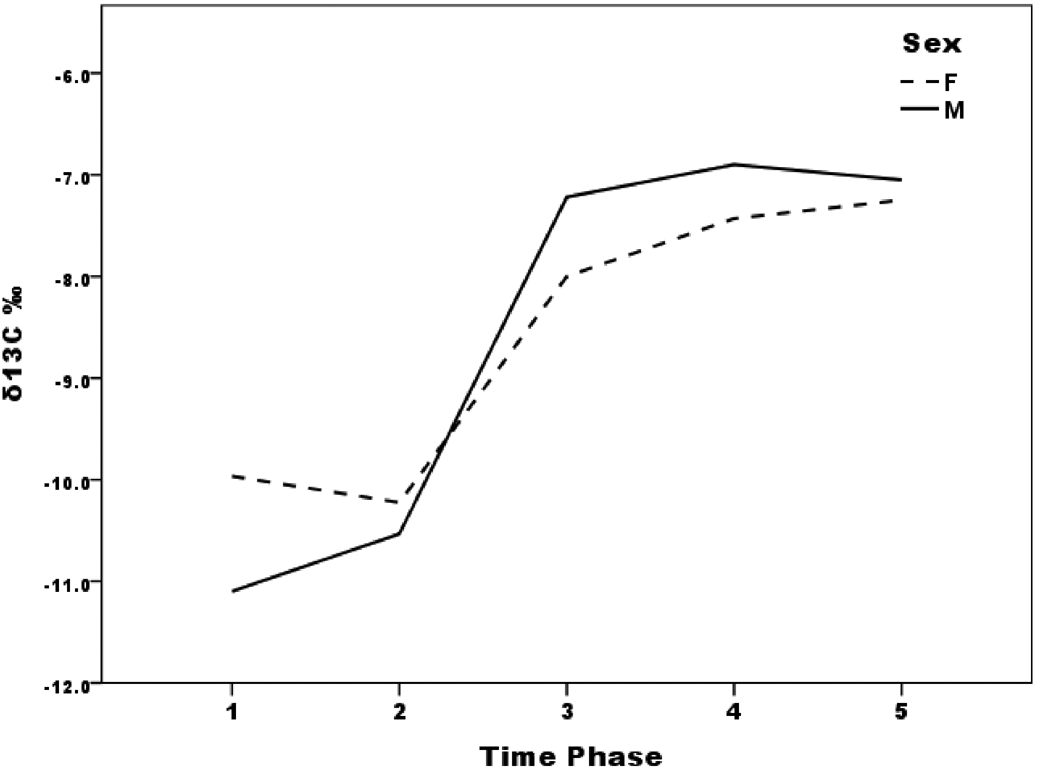

Figure 4. Sex differences in mean $\delta^{13}C_{apatite}$ values by phase. Phases: 1 = Guañape, 2 = Salinar, 3 = Pre-Structural Gallinazo, 4 = Structural Gallinazo, 5 = Post-Structural Gallinazo.

Discussion

The most notable pattern evident in the stable isotope data is significant enrichment in $\delta^{13}C_{apatite}$ values in the Gallinazo phase at Cerro Oreja. This enrichment could have occurred in three ways: (1) the Gallinazo phase occupants of Cerro Oreja could have increased their production of maize; (2) they could have intensified their use of marine resources; or (3) they could have intensified their production and use of maize and marine resources, respectively. Several lines of evidence suggest that this shift marks an agricultural transition toward maize intensification.

As noted above, archaeological investigations in the Moche Valley suggest an intensification of irrigation agriculture from the Guañape through Moche phases (Billman 2002). During the Guañape phase, settlement in the Moche Valley expanded as people moved inland and began canal construction (Billman 1996, 2002). Zooarchaeological and paleobotanical data from both coastal and inland sites suggests a diet with a protein component dominated by marine resources, but that included substantial terrestrial animal use and a wide variety of cultigens (Pozorski and Pozorski 1979). In the Salinar phase the irrigation system was expanded through new canal construction, increasing lands under cultivation by 73 percent from the preceding phase (Billman 2002). Zooarchaeological remains from Cerro Arena suggest a decrease in the use of marine resources during the Salinar phase (Pozorski 1979).

During the Gallinazo phase, much of the population of the valley aggregated at the valley neck at or near Cerro Oreja and on the coast at the site of Pampa Cruz, located at the modern community of Huanchaco (Billman 1996, 2002). Excavations of Gallinazo phase sites are very limited and no studies of Gallinazo phase food remains have been conducted. However, $\delta^{13}C_{apatite}$ values show a significant enrichment in ^{13}C, indicating a shift in food sources relative to the Salinar phase (Tables 3 and 5, Figure 3). Although this shift could represent a significant increase in the use of marine resources, perhaps through trade with Pampa Cruz, this seems unlikely to be the main source of ^{13}C enrichment given the location of Cerro Oreja and its population of perhaps more than 7,000 at the intake canals that supported the irrigation of thousands of hectares of high-quality arable land.

Comparisons between Cerro Oreja mean $\delta^{13}C_{apatite}$ values and those obtained for highly controlled diets in experimental animal studies offer one mechanism for interpreting the apatite data (Table 1). The normalized mean Gallinazo $\delta^{13}C_{apatite}$ value is –8.9‰ (–7.4‰ - 1.5‰). This value is nearest to the record for a pig (–9.0‰) that consumed a diet of 14 percent C_3 protein and 50 percent maize ($\delta^{13}C_{diet}$ = –18.0) (Howland et al. 2003). The next closest value reflects a diet of 20 percent marine fish and 35 percent maize (rat, –8.6‰; $\delta^{13}C_{diet}$ = –18.3) (Jim et al. 2004). Of the two animal samples, the closest match when body size and $\delta^{13}C_{collagen}$ values are also considered is the first. Although a single, nonhuman animal value is not definitive, it offers insight into which dietary emphasis may be indicated.

Comparisons between Cerro Oreja mean $\delta^{13}C_{apatite}$ values and those from archaeological human skeletal series with known diets provide another basis for interpreting the stable isotope results (Table 5). In this case, the two closest values to the Gallinazo mean $\delta^{13}C_{apatite}$ value of –7.4‰ derive from the marine dependent coastal prehistoric population of the Chiribaya site of San Gerónimo on the south coast of Peru (–8.3‰; Tomczak 2003:269) and a Mississippian population of maize farmers from the uplands of the Illinois River valley ($\delta^{13}C_{apatite}$ = –6.8‰; Hedman et al. 2002). The San Gerónimo value probably demarcates the upper $\delta^{13}C_{apatite}$ limits for a population obtaining their protein from sea resources and energy from C_3 plant foods in coastal Peru. The Gallinazo sample from Cerro Oreja is .9‰ more enriched in ^{13}C than this sample and is closer in all three $\delta^{13}C$ values ($\delta^{13}C_{apatite}$, $\delta^{13}C_{collagen}$ and $\Delta^{13}C_{CA\text{-}CO}$) to the Illinois upland maize farmers than to the San Gerónimo coastal population, suggesting a C_4 food component to the diet. The next closest apatite values are from the Chiribaya site of Yaral (–8.4‰; Tomczak 2003:269) and the Middle Horizon site of Ancón on the central coast (–6.0‰; Slovak and Paytan 2011:257). At Yaral, collagen and apatite values indicate a reliance on terrestrial animal and plant foods, including maize. At Ancón, both marine resources and maize were important in the diet, but intensive maize use appears to have shifted the Ancón apatite values to a mean $\delta^{13}C$ value 2.3‰ more positive than at San Gerónimo (–8.3‰) (Table 5). It seems unlikely that the noncoastal population at Cerro Oreja was as dependent on marine resources as either San Gerónimo or Ancón, suggesting that ^{13}C enrichment at Cerro Oreja was primarily, though not necessarily exclusively, due to maize consumption.

Dental data provide some of the most compelling supporting evidence for maize as the cause of ^{13}C enrichment during the Gallinazo phase at Cerro Oreja. As noted above, several indicators of dental disease show a significant increase from Salinar to Gallinazo phases, indicating that the diet became more cariogenic and that foods may have become more heavily processed. The frequency of carious adult teeth increased from 17 percent among females during the Salinar to 32 percent during the Pre-structural Gallinazo phase, and among males from 22 percent to 28 percent during the same period (Gagnon and Wiesen 2011:Table 3). Among children a similar trend was found, with the Salinar rate of 6 percent carious deciduous teeth increasing to 12 percent during the Pre-Structural Gallinazo phase (Gagnon 2006:155). During this same period dental abscessing increased from 10 percent to 14 percent among adult females and from 6 percent to 23 percent among adult males (Gagnon 2006:161), while antemortem tooth loss rates increased from 13 percent to 18 percent among adult females and 7 percent to 17 percent among adult males (Gagnon 2006:166)

Although not as definitive as the evidence of dental disease, patterns of dental trauma are consistent with the proposed shift in diet. The consumption of foods containing grit and other hard particles can result in enamel chipping (Milner and Larsen 1991; Turner and Cadien 1969). While chipping on anterior teeth most commonly results from use of the teeth as tools (Hutchinson 2002), trauma to posterior teeth is more often caused by chewing foods with grit and other inclusions (Milner and Larsen 1991). In particular, foragers have been shown to have higher rates of chipping than food producers as a result of more grit in the diet (Turner 1993). Shellfish also contain grit and sand, and shellfish consumption can therefore contribute to this type of dental damage (Sealy and van der Merwe 1998). At Cerro Oreja, rates of chipping among all teeth ranged from 25 percent to 35 percent in adults, with posterior teeth more often chipped than anterior teeth (Gagnon 2006:185). The rate of chipped adult teeth was highest during the Salinar phase (35 percent) and lowest during the Pre-Structural Gallinazo phase (25 percent), which suggests a shift from more grit-laden foods such as shellfish to more highly processed foods such as maize gruels or stews.

Collectively, these data indicate that the null hypothesis of a lack of change in the subsistence regime in the Gallinazo phase can be rejected. Instead, the data provide support for hypothesis H_A, of an intensification of maize agriculture during the Gallinazo phase in the Moche Valley. It is difficult to say what the mode of maize consumption was or how it might have changed during the period represented by the human remains from Cerro Oreja. Limited data on $\delta^{13}C$ values for matched bone apatite and tooth enamel from adult skeletons suggest that the adult diet was more enriched in ^{13}C than the diet of subadults during the Guañape phase, which may reflect greater consumption of marine foods by adults at that time (Figure 3). In the Salinar and Pre-Structural Gallinazo phases, the $\delta^{13}C$ values from bone apatite and tooth enamel were similar within each respective sample, albeit with greater variability evident among tooth samples due to the nature of tooth enamel formation and sampling. In the last two subphases of the Gallinazo phase, adults were consuming less ^{13}C enriched foods than subadults, suggesting that maize had become an important food for the young (6 months–12 years), perhaps in particular for porridges that sustained them during the weaning years (see Slovak and Paytan 2011:262). Unfortunately, without information on specific tooth types sampled in the enamel study (only tooth fragments of unknown type were sampled) this hypothesis cannot be tested. Clearly adults were also consuming maize, but to what extent this may have been in the form of *chicha de maíz* awaits further clarification.

Concluding Remarks

The shift in subsistence that heralded the Gallinazo phase ca. A.D. 1 did not immediately lead to the development of a regional political economy, as the Southern Moche state probably did not fully emerge in the Moche Valley until the A.D. 200s or perhaps even in the A.D. 300s (Billman 2010; Quilter and Castillo 2010). However, what these results indicate is that key changes occurred in the domestic and political economies well in advance of the dramatic expansion of the Moche political economy in the A.D. 300s. Our data suggest that farmers may have transitioned to the intensive production of maize in the Gallinazo phase. This intensification of production required farming families to invest more labor in cultivation, probably through such practices as shorter fallow periods and use of fertilizers. Generally speaking, peasant farmers intensify production because of population pressure, market demands, or tribute demands of the political economy (Netting 1993). Given the absence of any evidence of population growth in the valley (Billman 1996; Gagnon and Wiesen 2011) or changing market conditions during the Gallinazo phase (Billman 1996, 1997), this shift in diet and agricultural practices may have been caused by the increased demands of the Cerro Oreja polity. If this was the case, then this signals a fundamental change in the relationship between farmers and rulers. In short the Gallinazo phase economic shift may have established the political economic relationships that were key to the dramatic expansion of the power of Moche leaders in the Middle Moche phase. In this sense, Castillo's (2009:227) prediction that increased agricultural productivity provided the necessary preconditions for the political developments in the Moche period finds support in the archaeological record of the Moche Valley, where the greatest monuments to Moche power and ingenuity were first constructed.

Additional work in the domestic sector at Cerro Oreja is needed to further elucidate the economic transition identified in this study, particularly as it pertains to agricultural intensification, the production and use of maize products, and the acquisition and consumption of marine resources. Comparative stable isotope research on the Pampas Cruz population is also needed to clarify the nature of the economic relationship between Cerro Oreja and this contemporaneous coastal community, a relationship that could have played a pivotal role in the development of the political economy that ultimately gave rise to the Southern Moche state.

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Notes

1. In this article we use the name "Southern Moche state" for the regional political economy that emerged at Huacas de Moche in the Moche Valley during the first few centuries A.D. We use this name as a term of convenience. We wish to avoid arguments over "whether or not Moche was a state," and to focus instead on the nature of Moche political relationships, especially the nexus of the political economy and the domestic economy. In short, how power was negotiated between heterogenous groups of rulers and farming, fishing and crafting households.

2. Sequential page numbers were assigned to this unnumbered report; the introduction is page 1.

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