

## Chapter 2

### Mid-Holocene climate and culture change in coastal Peru

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#### Abstract

*In the general absence of standard, high-resolution paleoclimatic records such as lake cores or corals, archaeological remains from Mid-Holocene archaeological sites in coastal Peru provided pioneering interpretations of El Niño/Southern Oscillation (ENSO)-related paleoclimatic change in the eastern equatorial Pacific that have since been supported and amplified by multiple proxies. At the same time, archaeologists working in the region have explored the role of climatic change in cultural development, with particular attention to El Niño. In this chapter we review the history of study and the current status of Mid-Holocene climatic and cultural change along the Peruvian coast, with a focus on major transitions at ca. 5800 and 3000 cal yr BP that correlate temporally with changes in ENSO frequency.*

#### 1. Introduction

In the wake of several large-scale El Niño events over the last quarter century, archaeologists, geologists, and paleoclimatologists have shown an increasing interest in reconstructing the prehistory of this climatic anomaly. Mollusks found in archaeological sites on the north and central coasts of Peru provided the first clues that El Niño frequency had varied significantly throughout the Holocene. The totality of archaeological and paleoclimatic data available at this time support a major change in tropical Pacific climate at about 5800 cal yr BP (Rollins et al., 1986; Sandweiss et al., 1996, 2001; radiocarbon dates used in this paper were calibrated

with Calib 4.3 (Stuiver et al., 1998a, b)), though it is now unclear whether El Niño was absent or just extremely rare for several millennia prior to that date. Molluscan remains from Peru also suggest that between ca. 5800 and 3000 cal yr BP, El Niño was present but less frequent than today. Modern, rapid recurrence intervals were apparently achieved only after that time (Sandweiss et al., 2001).

Here, we review available data from multiple Central Andean archives (both anthropogenic and natural) for the evolution of El Niño between ca. 9000 and 3000 cal yr BP. Turning then to the archaeological record, the onset of El Niño at 5800 cal yr BP is temporally correlated with the beginning of monumental construction on the Peruvian coast, while the apparent increase in El Niño frequency after 3000 cal yr BP is correlated with the abandonment of monumental, Initial Period temples in the same region. Is there a causal link between these processes?

## **2. The Peruvian archaeological record of Holocene El Niño frequency variation**

In 1980, thanks to a tip from David Wilson, Sandweiss first visited the fossil beach and associated archaeological sites of the Ostra Complex (see Fig. 2.1 for the location of sites mentioned in the text). Located just north of the Santa river on the north-central Peruvian coast (9°S), these archaeological and paleontological deposits date to about 5800 to 7150 cal yr BP (Rollins et al., 1986; Perrier et al., 1994; Sandweiss et al., 1996; Andrus et al., 2003). A return visit several months later with Rollins and Richardson led to the hypothesis that the Ostra sites reflect a time when El Niño did not function as it does today (Rollins et al., 1986; Sandweiss, 1986, 1996, 2003; Sandweiss et al., 1983, 1996, 1997, 1998a, 2001).

Situated on the shores of a now-dry embayment, the principal sites of the Ostra Complex are the Ostra Base Camp (OBC), located on the southern end of the fossil bay, and the Ostra Collecting Station (OCS, Fig. 2.2), located on a rocky knoll about halfway along the shore of the fossil bay. On our first visit, we noticed that both the sites and the fossil beach contained mollusk species no longer present in the area – in fact, they are now found more than 4° of latitude to the north, near the Equator (Sandweiss et al., 1983). At Ostra, we found the same mollusks in living position in the former bay, indicating that the site's inhabitants were collecting their shellfood from the adjacent beach rather than from distant shores. Throughout this chapter, we will refer to assemblages like those from the Ostra Complex as warm-water molluscan assemblages; we will use the term “cool-water assemblages” for the Peru current-adapted species found at later sites; technically, these are “warm-tropical” and “warm-temperate”, respectively. Reitz later identified similar assemblages for the fish fauna (Reitz and Sandweiss, 2001; see also Reitz et al., in press).

On the same 1980 expedition, we visited another series of sites on the shores of the Salinas de Chao, a second dry embayment 20 km further north. The earliest of these sites dated between ca. 3700 and 5350 cal yr BP and contained only cool-water mollusks characteristic of Peru and Chile today (Cárdenas, 1979, 1995; Sandweiss et al.,



Figure 2.1. Map showing the location of sites mentioned in the text.

1983; Perrier et al., 1994; Andrus et al., 2003). Molluscan assemblages had clearly changed sometime in the centuries immediately following 5800 cal yr BP. Further north, near Talara, Peru, Richardson (1973, 1978) had observed a similar change from warm-water mangrove mollusks to cool-water species, also around 5800 cal yr BP.

We considered several hypotheses to explain these data. Was the thermally anomalous molluscan assemblage (TAMA) the result of local conditions such as solar warming of shallow embayments, or did it reflect a climatic regime different



*Figure 2.2.* View from the Ostra Collecting Station SSW across the fossil bay towards the Ostra Base Camp. Photo by D.H. Sandweiss.

from today? Several factors convinced us that the latter scenario was more likely correct: (1) the similar nature and timing of change at two widely separated locales in different geographic settings; (2) the restriction of warm-water molluscan assemblages to the north coast of Peru and to sites dating before 5800 cal yr BP; (3) the presence of multiple year age classes in the molluscan assemblages, both in the beach and in the sites, indicating that local conditions must have allowed sufficient exchange with the open ocean to prevent hypersalinity; and (4) the moderate diversity of the molluscan assemblages, suggesting long-term stability rather than environmental stress. We thus concluded that for some time prior to 5800 years ago, the coast of Peru north of ca. 10°S latitude was characterized by permanent warm water. From these data, we hypothesized that El Niño did not operate for some period before 5800 cal yr BP; after that time, we saw conditions as essentially the same as today (Rollins et al., 1986).

In 1990, Thomas J. DeVries and Lisa E. Wells (1990) suggested that the presence of a warm-water molluscan fauna at the Ostra sites might be due to solar warming in a completely enclosed lagoon, rather than a change in ocean circulation. The idea of anything living in a completely enclosed lagoon seemed unlikely – at this latitude and in the absence of annual rainfall, such a lagoon would rapidly go hypersaline and then dry up completely. Nevertheless, to test their idea of warm water only behind a barrier, with “normal” cold water immediately offshore of the barrier, Sandweiss returned to the Ostra sites in 1991 to recover a more extensive collection of fish as well as molluscan remains. Fish provide another source of climatic data

(Sandweiss et al., 1996; Reitz and Sandweiss, 2001; Reitz et al., in press). In 1995 and again in 2001, Richardson and Sandweiss excavated at the Siches site ( $4^{\circ}30'S$ ), near Talara, for the same purpose (Sandweiss et al., 1996; Sandweiss, 2003).

Sandweiss and colleagues (1996) compiled the Mid-Holocene archaeological record then available from the Peruvian coast, with particular attention to the marine fauna. These data clearly showed change at 5800 cal yr BP and north of  $10^{\circ}S$  latitude. For several millennia prior to that date, northern Peruvian sites contain predominately warm-water molluscan and (where known) fish faunas, whereas after 5800 cal yr BP for the entire Peruvian coast, and south of  $10^{\circ}S$  prior to 5800 cal yr BP, they contain predominately cool-water mollusks and fish.

Additional insight into the climatic conditions reflected by the pre-5800 cal yr BP, Mid-Holocene marine fauna in coastal sites north of  $10^{\circ}S$  came from Andrus's geochemical analyses of growth increments in fish otoliths from OBC and Siches (Andrus et al., 2002a, 2003) and in a mollusk from OBC (Andrus et al., 2005). Delta  $^{18}O$  of the otoliths showed that in the millennium preceding 5800 cal yr BP, average sea surface temperature (SST) was about  $3\text{--}4^{\circ}C$  warmer than today, consistent with our interpretation of the marine fauna. However, the seasonal structure of SST showed a more complex picture. At Siches ( $4^{\circ}30'S$ ), the annual SST cycle in the Mid-Holocene paralleled that of today but was offset by  $3\text{--}4^{\circ}C$ . In contrast, at OBC winters were about as cool as today but summers were significantly warmer (Andrus et al., 2002a); the amplitude of seasonal temperature at OBC was apparently the same as the difference between normal to El Niño year SSTs today, but had an annual rather than interannual cycle. This pattern explains the difference between molluscan and fish fauna assemblages at OBC. Mollusks are sessile and therefore controlled by maximum annual temperature; OBC contained only species that can survive in warm water. Fish are mobile, so during the cool summers, cool-water fish could move north to the Ostra area while the warm-water fish would be present during the warm summers. The OBC fish fauna was dominated by warm-water species but included some cool-water fish as well (Reitz and Sandweiss, 2001).

Experiments on mollusks that survived the 1982–83 El Niño event showed that the  $^{14}C$  content changed across the event. In growth increments deposited before and after El Niño,  $^{14}C$  was significantly older than modern, reflecting the old, deep upwelled water of the Peru Current. During El Niño,  $^{14}C$  gave an age close to modern, reflected the upwelling of mixed surface water resulting from the depression of the thermocline (Andrus et al., 2005). Preliminary analysis of  $^{14}C$  in a Mid-Holocene mollusk from OBC compared to the  $^{14}C$  age of charcoal from the same context suggests decreased upwelling compared to today, again consistent with our interpretation of Mid-Holocene climate at this locale (Andrus et al., 2002b).

In the late 1990s, further consideration of the molluscan record in Mid-Holocene Peruvian coastal sites led to additional insight (Sandweiss et al., 2001). We noticed that sites immediately post-dating the postulated onset of El Niño at 5800 cal yr BP had molluscan assemblages dominated by two species that are extremely sensitive to warm water. The large purple mussel *Choromytilus chorus* has an LT-50 (lethal temperature-50, the temperature at which 50% of the population dies in 24 h) of

28°C, based on studies in Chile (Urban, 1994). Although we do not have LT-50 data for *Mesodesma donacium*, this wedge clam was fished commercially as far north as Lima (12°S) before the 1982–83 El Niño, after which its northern limit shifted south to Lomas (15°30'S). Following the 1997–98 El Niño, the Peruvian government was forced to ban fishing of *Mesodesma* anywhere in Peru. The abundant presence of these two species in coastal sites between Lima and Trujillo (8°S) during the Late Preceamic and Initial Periods (ca. 5800–3000 cal yr BP) would not have been possible with an El Niño recurrence interval as short as it is today. The disappearance of the two mollusk species from north-central and northern Peruvian sites after 3000 cal yr BP strongly suggests an increase in El Niño frequency at that time (Sandweiss et al., 2001).

Table 2.1 summarizes the archaeological record of Terminal Pleistocene to Mid-Holocene climatic change along the Peruvian coast. The data are discussed in greater detail in Sandweiss (2003). This broad review of excavation results from multiple projects supports the outlines of Holocene change detailed from our own work (Sandweiss et al., 1996, 2001), with clearly marked transitions in the behavior of El Niño at ca. 5800 and 3000 cal yr BP.

Our most recent work on El Niño frequencies concerns the late prehispanic period. At the Inca-period fishing site Lo Demás, Sandweiss (1992) found that fish remains in the earliest deposits, ca. AD 1480–1500, were dominated by anchovies (*Engraulis ringens*), while the later deposits (ca. AD 1500–1540) contained more sardines (*Sardinops sagax*). Chavez et al. (2003) analyzed fisheries data for the Peruvian coast over the entire 20th century and compared them to Pacific climate records, finding a 50-year cycle of alternating anchovy regimes (slightly cooler average sea surface temperature (SST), less frequent El Niño) and sardine regimes (slightly warmer SST, more frequent El Niño). The faunal record from Lo Demás mirrors the regime change from anchovy to sardine, suggesting a slight change in El Niño frequency at about AD 1500 (Sandweiss et al., 2004). This transition accords with the scant Pacific Basin historical record (Quinn, 1992) and the Quelccaya ice core record (Thompson, 1992). Looking at faunal records from earlier sites, we see the potential to identify similar decadal-scale change in El Niño frequency.

### 3. Mid-Holocene climate from natural archives

Present-day climatic variability on interannual time scales in the tropics is dominated by El Niño/Southern Oscillation (ENSO), which involves both the atmosphere and the ocean in the tropical Pacific (e.g., Maasch, in press). Through teleconnections, extratropical climatic variability on these time scales is also impacted by ENSO.

ENSO seems to be locked in phase with the seasonal cycle, but it is not periodic (i.e., El Niño events occur at unevenly spaced intervals). The magnitude and duration of individual events vary. Over the last century (the time span of reliable instrument records) the frequency and duration of ENSO events has changed (e.g., Rajagopalan et al., 1997; Maasch, in press). Over long periods of time

Table 2.1. Climatic signals from terminal Pleistocene to Mid-Holocene archaeological sites on the Peruvian coast (after Sandweiss, 2003).

Site (S lat)	Terminal Pleistocene ~13000–11,000 cal BP	Early Holocene ~11000–9000 cal BP	Mid-Holocene ~9000–3000 cal BP		Basic references
			Mid-Holocene I ~9000–5800 cal BP	Mid-Holocene II ~5800–3000 cal BP	
Siches (4°30'S)	–	–	Warmer SSTs/seasonal precipitation/No ENSO	Cool SSTs (modern)	Sandweiss et al. (1996), Andrus et al. (2002a)
Amotape (4°40'S)	Warmer SSTs/less arid	Warmer SSTs/less arid	–	–	Richardson (1978)
Quebrada Chorrillos (6°S)	–	–	Warmer SSTs/No ENSO	–	Cárdenas et al. (1993)
Avic (6°S)	–	–	–	Cool SSTs (modern)	Cárdenas et al. (1993)
Paján (8°30'S)	Warmer SSTs/less arid	Warmer SSTs/less arid	–	–	Chauchat et al. (1992)
Moche Valley Late Preceramic/Initial Period sites (8°10'S)	–	–	–	Cool SSTs (modern)/low frequency ENSO	Pozorski (1979)
Salinas de Chao (8°40'S)	–	–	–	Cool SSTs (modern)/low frequency ENSO	Sandweiss et al. (1996)
Ostra (8°55'S)	–	–	Warmer SSTs/seasonal precipitation/High amplitude seasonal SST cycle/No ENSO	–	Sandweiss et al. (1996), Andrus et al. (2002a)

Continued

Table 2.1. continued

Site (S lat)	Terminal Pleistocene ~13000–11,000 cal BP	Early Holocene ~11000–9000 cal BP	Mid-Holocene ~9000–3000 cal BP		Basic references
			Mid-Holocene I ~9000–5800 cal BP	Mid-Holocene II ~5800–3000 cal BP	
Huaynuñá (9°30'S)	–	–	–	Cool SSTs (modern)/low frequency ENSO	Pozorski and Pozorski (1990)
Casma Valley Late Preceramic/ Initial Period sites (9°30'S)	–	–	–	Cool SSTs (modern)/low frequency ENSO	Pozorski and Pozorski (1987)
Almejas (9°40'S)	–	–	Warmer SSTs/No ENSO	–	Pozorski and Pozorski (1995)
PV 35-106 (10°S)	–	–	Slightly warmer SSTs?	–	Bonavia (1996)
PV 35-6 (10°S)	–	–	–	Cool SSTs (modern)/low frequency ENSO	Bonavia et al. (1993)
Los Gavilanes (10°S)	–	–	–	Cool SSTs (modern)	Bonavia (1982)
As8 (10°45'S)	–	–	Slightly warmer SSTs?	–	Feldman (1980)
Aspero (10°45'S)	–	–	–	Cool SSTs (modern)/low frequency ENSO	Feldman (1980)



Caral (10°45'S)	-	-	-	-	Cool SSTs (modern)/low frequency ENSO	Shady Solis et al. (2001)
Paloma (12°30'S)	-	-	-	-	Cool SSTs (modern)	Reitz (1988)
Quebrada Jaguay (16°30'S)	-	-	-	-	Cool SSTs (modern) / greater highland precipitation?	Sandweiss et al. (1998b)
Ring Site (17°40'S)	-	-	-	-	Cool SSTs (modern)	Sandweiss et al. (1989)
Quebrada Tacahuay (17°48'S)	-	-	-	-	Cool SSTs (modern) / ENSO floods	Keefer et al. (1998), deFrance et al. (2001)
Quebrada de los Burros (18°00'S)	-	-	-	-	Cool SSTs (modern) / ENSO floods late	Fontugne et al. (1999), Lavallée et al. (1999)

(centuries-millennia), the recurrence interval and amplitude of ENSO have been even greater in magnitude than those observed in the instrument record.

Continuous natural Holocene paleoclimate archives from northern Peru, Ecuador, and the eastern tropical Pacific Ocean are difficult to find, privileging anthropogenic deposits from archaeological sites. Lakes along the desert coast are ephemeral or non-existent. Coastal waters are too cold for corals, and although sedimentation rates are high along the Peru margin, hiatuses and/or disturbance due to turbidite flows in the Holocene part of the record are common. Nevertheless, there are some high-to-medium resolution records from the region that reflect aspects of the Holocene climate of coastal Peru, as well as some low-resolution records of relevance to millennial-scale climatic variation. Although precisely dating these records is difficult, climatic change determined from them is consistent with results obtained from mollusk and fish remains from archaeological sites as described above. We discuss these regional paleoclimate records below.

### *3.1. Terrestrial records (low-scale resolution)*

Flood deposits, soil development, lomas (xerophytic vegetation) distribution, and beach ridge morphology all offer low temporal resolution records of coastal climate in Peru. Dated flood events from the Peruvian coast reflect long-term variation in torrential rainfall events. Quebrada de los Burros (18°S) is a narrow canyon on the western slopes of the southern Peruvian Andes. Fontugne et al. (1999) identified and dated a series of debris flows in this canyon. Because it heads in the hyperarid region below the altitude of seasonal rainfall, the debris flows almost certainly represent extreme precipitation associated with El Niño events. The Quebrada de los Burros flood record has a hiatus between ca. 9600 and 3400 cal yr BP; the sedimentary record for this interval is characterized by organic layers interpreted as indicators of “a permanent water supply resulting from an increased condensation of fog at mid-altitudes” due to enhanced coastal upwelling (Fontugne et al., 1999, p. 171). The organic layers are inconsistent with El Niño activity in this region. Burros is associated with a Mid-Holocene archaeological deposit.

Half a degree north of Quebrada de los Burros, Quebrada Tacahuay is another dry canyon heading below the altitude of seasonal rainfall. There, too, a dated flood record shows a Mid-Holocene hiatus between ca. 8900 and 5700 cal yr BP (Keefer et al., 1998, 2003). This span is almost perfectly coincident with the hiatus in El Niño activity postulated from the archaeological record of coastal Peru. At Tacahuay, the flood deposits separate several episodes of human occupation from the Terminal Pleistocene to the early Mid-Holocene.

Noller’s (1993) study of Quaternary soil development along the Peruvian coast shows a major disjunction at 12°S. South of that point, the absence of significant soil development and the presence of soluble minerals and salts indicate long-term hyperaridity. North of 12°S, greater soil development and the absence of significant salt accumulations document periodic rainfall events. This pattern is consistent with

a period of seasonal rainfall in the Mid-Holocene; the seasonal SST structure reconstructed by Andrus et al. (2002a) for OBC would result in seasonal precipitation along the north coast during this time.

Noller's soil record is also consistent with the patterns of endemism and adaptation in lomas (fog-based) plant communities in the western foothills of the Andes, overlooking the coast. Rundel and Dillon (1998; Rundel et al., 1991) identify northern and southern Peruvian lomas-flora units with a boundary at 12°S. The southern unit, with a high degree of endemism in each lomas stand, indicates long-term hyperaridity. The northern unit shows greater similarities between now-isolated lomas stands, suggesting periods of greater moisture in the past, when the lomas were continuous. A Mid-Holocene interval of seasonal rainfall would help explain the pattern of lomas endemism.

The northern coast of Peru has five major beach ridge plains, at Santa, Piura, Colán, Chira, and Tumbes. Over the last 30 years, all but Tumbes have been studied in some detail (see Shafer et al., 2004). The Peruvian beach ridges are composed of cobbles (Santa, Colán) or sand (Piura, Chira, Tumbes) and with the exception of Colán are built by material from the four highest flow rivers of the Peruvian coast. All the ridges post-date sea level stabilization and the return of El Niño after 5800 cal yr BP.

We have hypothesized that ridges form when sediment produced by seismic activity is flushed by El Niño-caused torrential rainfall from the unvegetated desert surface of the coast and western slopes into the rivers; the increased competence of the rivers during ENSO rainfall events washes the material out to the shore, where a delta forms and then is reworked in the direction of longshore drift (north) to form the ridges (Sandweiss et al., 1983; Sandweiss, 1986). Internal ridge morphology (*ibid.*) and remote sensing studies of coastal change at Santa (Moseley et al., 1992) and Chira (Shafer et al., 2004) support this hypothesis.

Each ridge set contains eight or nine major ridges, though each of these is probably a composite of multiple formation events. In each case except Colán, the oldest two or three ridges are larger amplitude and better defined, while the final six ridges are lower amplitude, higher frequency, and less well defined. Based on available dates, most from the Chira ridges (Richardson, 1981; Ortlieb et al., 1993), the transition from high- to low-amplitude ridges occurs around 3000 cal yr BP, when we have identified a shift from less to more frequent El Niño events (Shafer et al., 2004). With a longer recurrence interval between rainfall episodes, there would be more time for multiple seismic events to accumulate material on the landscape, resulting in fewer but larger ridges. After 3000 cal yr BP, more frequent torrential rainfall would flush the landscape more often, leading to more but smaller ridges.

### ***3.2. Paleolimnological data (medium-scale resolution)***

Nearly continuous Holocene proxy climate records have been recovered from the Galápagos Islands and from highland lakes in Ecuador, Chile, and Bolivia, though

not from the desert coast of Peru. Laguna Pallcacocha, Ecuador ( $2^{\circ}46'S$ ,  $79^{\circ}14'W$  and 4060 masl), analyzed by Rodbell et al. (1999) and Moy et al. (2002), contains sediments with rainstorm-related inorganic laminae. The layers containing clastic sediments that were washed into the lake during storms, measured using gray-scale and color light reflectance, match the historic record of El Niño events for the last 200 years. Using them as a proxy for El Niño, Rodbell et al. (1999) found that from Late Glacial to early Holocene (15,000 to about 7000 cal yr BP), the periodicity of elevated clastic deposition was decadal (greater than or equal to 15 years). Beginning at  $\sim 7000$  cal yr BP, storm-induced clastic events came about 10–20 and 2–8.5 years apart. After  $\sim 5000$  cal yr BP 2–8.5-year periodicities were most dominant, more consistent with modern El Niño frequency.

Riedinger et al. (2002) examined lithostratigraphic and mineralogic properties of sediments from hypersaline Bainbridge Crater Lake, Galápagos Islands. These laminated sediments also provide proxy evidence of past El Niño frequency and intensity. The Bainbridge record suggests that between  $\sim 7100$  and 4600 cal yr BP El Niño activity was present, but infrequent. This record also indicates that the frequency and intensity of El Niño events increased at about 3100 cal yr BP.

Jenny et al. (2002) obtained a multi-proxy Holocene climate record from Laguna Aculeo in central Chile ( $33^{\circ}50'S$ ,  $70^{\circ}54'W$ ). This record showed an arid Early to Mid-Holocene period (ca. 9500–5700 cal yr BP). After 5700 cal yr BP effective moisture increased progressively and, around 3200 cal yr BP, modern humid conditions were established. Early Holocene flood deposits, indicative of wet winters, were absent until 5700 cal yr BP. These become frequent after 3200 cal yr BP. This evidence is consistent with weak or no El Niño activity during the Early and Mid-Holocene, followed by infrequent El Niño events and then increased El Niño frequency in the late Holocene. The Laguna Aculeo chronology matches the archaeological chronology of Holocene climatic change from the Peruvian coast almost perfectly. Lake Titicaca, located between Bolivia and Peru (at about  $16^{\circ}$  to  $17.50^{\circ}S$ ,  $68.5^{\circ}$  to  $70^{\circ}W$ , 3810 masl) can be used as a recorder of the precipitation over a large portion of tropical South America. Using lake cores spanning the last 25,000 years, Baker et al. (2001) have shown that maximum aridity and lowest lake level occurred in the early and middle Holocene (8000 to 5500 cal yr BP). The lowest level of Lake Titicaca was reached between 6000–5000 cal yr BP after which lake level rose to close to its modern level. During ENSO events, the Titicaca Basin tends to suffer drought; lake level rise from the mid-Holocene low stand is generally coincident with our period of infrequent ENSOs and cool coastal conditions when drought frequency may have been reduced.

### ***3.3. Marine records (medium- to high-resolution)***

Several marine sediment cores from near the coast of Peru and Chile have produced continuous climate proxy records at a resolution high enough to reconstruct Late Glacial to Holocene ENSO variability.

Rein et al. (2005) analyzed a 20,000 year-long, high-resolution marine sediment record from the El Niño region of Peru (core 106KL from 80 km off Lima/Peru; 12°03'S, 77°39.8'W, 184 m). Estimates from 106KL for past sea surface temperature, photosynthesis pigments, and a lithic proxy for El Niño flood events served as a proxy for past ENSO variability. Rein et al. (2005) concluded that an Early Holocene maximum of El Niño activity was followed by weak El Niño activity during the Mid-Holocene period (8000–5600 cal yr BP). The frequency and intensity of El Niño activity with thickest El Niño flood deposits increased after about 3000 cal yr BP. This record, too, fits our archaeologically-based reconstruction of Holocene ENSO frequency.

Lower-resolution marine records from the eastern equatorial Pacific analyzed by Loubere et al. (2003) were used to reconstruct thermocline mixed layer temperatures and nutrient contents. Stable isotopes and assemblage data from benthic and planktonic foraminifera measured in three deep-sea cores obtained off the coast of northern Peru indicate that changes in the thermocline and mixed layer consistent with increased upwelling of cooler waters began sometime after around 7000 cal yr BP.

#### **4. Cultural records**

Peruvian coastal archaeological sites contain or are associated with a variety of records pertinent to reconstructing El Niño behavior over the last 13,000 years, as reviewed above in Sections 2 and 3. These include biogeography (e.g., Reitz and Sandweiss, 2001; Reitz et al., in press; Sandweiss et al., 1996), growth increment analysis (e.g., Rollins et al., 1986, 1987), and biogeochemistry (e.g., Andrus et al., 2002a, 2002b, 2005) of mollusks and fish, differential preservation of soft organic materials, stylistic connections between distant regions sharing similar environments (Sandweiss, 1996), flood deposits (e.g., Keefer et al., 2003), and beach ridge morphology (e.g., Sandweiss, 1986; Shafer et al., 2004).

Peruvian sites also demonstrate change through time in cultural attributes that correlate temporally with the changes we have identified in El Niño frequency in the Mid-Holocene (Sandweiss et al., 2001; Sandweiss, 2003; Richardson and Sandweiss, in press). Major indicators of cultural change include settlement pattern (the distribution and function of sites across the landscape), construction style (size, form, and function of monuments as well as dwellings), subsistence practices, long-distance exchange or contact, symbolic content of artifacts and structures, and burial patterns. In this section, we focus on large-scale changes in settlement pattern, construction style, and subsistence. In terms of cultural chronology, the relevant periods are the Early Preceramic Period (ca. 13000–9000 cal yr BP), the Middle Preceramic Period (ca. 9000–5800 cal yr BP), the Late Preceramic Period (ca. 5800–4100 cal yr BP), and the Initial Period (ca. 4100–2800 cal yr BP).

Prior to 5800 cal yr BP, no large-scale monumental architecture has been identified in coastal Peru, and only a few small structures are known elsewhere in the region, as at Nanhoc on the western slopes of the northern Peruvian Andes

(Dillehay, 1992; Netherly and Dillehay, 1986). Coastal sites in the millennia preceding 5800 cal yr BP range from small fishing camps such as Early to Middle Preceramic Quebrada Jaguay (16°30'S, Sandweiss et al., 1998b) and Siches (4°30'S, e.g., Richardson, 1973, 1978; Sandweiss et al., 1996) and Middle Preceramic Ostra Base Camp (8°55'S, e.g., Sandweiss, 1996; Sandweiss et al., 1996) to villages such as Paloma (12°30'S, e.g., Benfer, 1990). Early and Middle Preceramic coastal sites had subsistence systems based on marine resources, wild plants, and occasionally early domesticated plants (Sandweiss, in press). North of 10°S, marine organisms recovered from these sites are predominately warm-water species (e.g., Sandweiss et al., 1996; Reitz and Sandweiss, 2001; Reitz et al., in press; see Section 2).

Human populations in Peru grew through time (e.g., Rick, 1987) and consequently created more and larger archaeological sites. Combined with the stabilization of sea level during the Mid-Holocene, this demographic trend resulted in an increasing number of sites preserved for analysis. In the following paragraphs, we review data for the best-known Late Preceramic and Initial Period coastal sites (see Table 1 and Moseley, 2001; Burger, 1992, *inter alia* for other sites of this time).

#### 4.1. Late Preceramic Period

Coastal monuments first appear during the Late Preceramic Period, after the climatic transition at 5800 cal yr BP. Although Late Preceramic mounds are distributed between Lima (12°S) and the Salinas de Chao (8°40'S), it is now clear that the first florescence of monument building in coastal Peru took place on the North Central Coast (aka Norte Chico) between about 10°S and 11°S. At Aspero (10°45'S) on the shore of the Supe Valley, Feldman (1980, 1985) excavated several small, early temple mounds, but only recovered materials from the last several construction phases. These phases date to ca. 5000–4300 cal yr BP. However, Feldman also obtained one anomalously early date of ca. 5650 cal yr BP on charcoal that may have been recycled from an earlier construction phase and may therefore indicate an onset of monument building as early as that date.

Subsistence at Aspero was based on fishing, farming, and gathering. All the marine species are typical, cool-water Peru Current taxa. Among the mollusks, *Choromytilus chorus* and *Mesodesma donacium* were particularly important. The most important domesticated plants were cotton (*Gossypium barbadense*, for nets and textiles) and gourd (*Lagenaria siceraria*, for floats and containers) (Feldman, 1980), utilitarian species which Moseley (1975) calls industrial plants. Though present in Peru by the Late Preceramic Period (e.g., Perry et al., 2006), maize was not a dietary staple on the coast.

Though known for decades as Chupacigarro Grande (e.g., Kosok, 1965), the site now called Caral (10°45'S) (Fig. 2.3) was not proven to be Late Preceramic in age until recently (Shady Solís et al., 2001). A suite of radiocarbon dates, many on short-lived plants used in construction, place the site between about 4600 and 3900 cal yr BP (*ibid.*). Called the New World's first city, Caral is a complex settlement

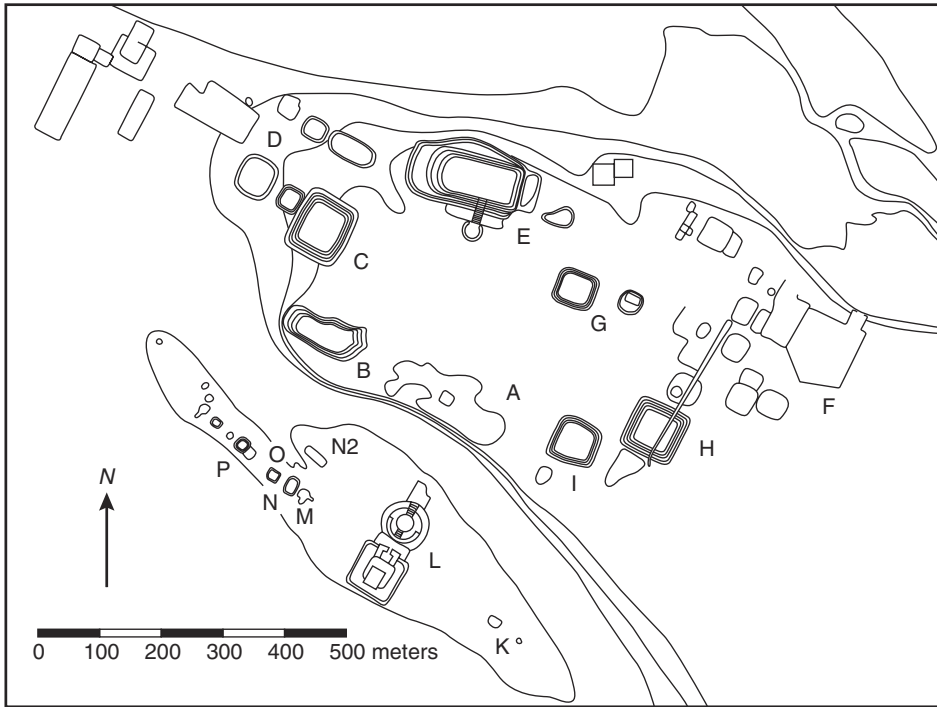


Figure 2.3. Plan of Caral (top, after Shady Solis et al., 2001) and photo of mounds G, H, and I at Caral, taken from Mound E (the Great Temple). Photo by D.H. Sandweiss.

with six large mounds and residential areas with different kinds of architecture suggesting different social classes (ibid.; Shady Solís and Leyva, 2003; Shady Solís, 2005). In contrast to Aspero, Los Morteros, and other Late Preceramic monumental sites known before 2001, Caral is located about 25 km inland, up the same valley as Aspero. Work by Shady Solís elsewhere in the Supe Valley, and more recently by Haas et al. (2004) in neighboring valleys, has uncovered more inland Late Preceramic centers with mounds.

Though subsistence data for the sites located by Haas have not been published in detail (the sites have only been tested to acquire samples for dating), Caral has been extensively excavated for over a decade, and the full panoply of remains are being analyzed by R. Shady's multidisciplinary team (e.g., Shady Solís and Leyva, 2003; Shady Solís, 2005). Despite the distance from the shore, the animal diet came almost entirely from the ocean. As elsewhere on the North Central Coast and Central Coast, *Choromytilus* and *Mesodesma* were dominant molluscan species, the most abundant fish were sardines (*Sardinops sagax sagax*) and anchoveta (*Engraulis ringens*), and the most common plants were cotton and gourd.

Los Morteros is a large mound on the fossil bay at Salinas de Chao (8°40'S). Radiocarbon dates on materials from shallow excavations date the final occupation of the structure to ca. 5500–5100 cal yr BP (Cárdenas, 1979, 1995); the structure itself is earlier, though how much earlier is unknown at this time. Molluscan remains from this site are typical cool-water Peru Current species. Los Morteros is the northernmost Late Preceramic monumental structure on the Peruvian coast.

Near Lima, El Paraíso is a large aceramic site with dates falling at the end of the Late Preceramic Period and overlapping the Initial Period (ca. 4100–3200 cal yr BP; Quilter, 1985; Quilter et al., 1991). The site covers about 58 ha and consists of six large mounds and at least five smaller structures. Though test excavations failed to find evidence for a large resident population, primary midden did provide insight into diet (Quilter et al., 1991) and climate (Sandweiss et al., 1996). Like other Late Preceramic sites, mollusks and fish provided most of the animal food, while plant food was a combination of wild and domesticated taxa. Once again, the most important crops were cotton and gourd.

Although modest-sized permanent settlements such as Asia Unit 1 (12°30'S; Engel, 1963) have been found south of Lima, El Paraíso is the southernmost Late Preceramic monumental site known to date.

Debate continues about the temporal priority of shoreline vs. inland centers in the Late Preceramic Period (Haas and Creamer, 2006; cf. Sandweiss, 2006), but the weight of evidence currently available supports a sequence beginning on the coast with fishing/farming sites, with later population growth driving expansion inland to increase production of cotton and gourds to intensify the fishing industry (Sandweiss and Rademaker, 2006; Sandweiss, in press). How complex Late Preceramic societies really were continues to be debated, but the recent work at Caral and the other North Central Coast monumental sites supports earlier arguments for social stratification, at least in the core region between about 12° and 8°S. The North Central Coast was the center of Late Preceramic development, with the greatest number, size, and



complexity of monumental sites. In this pristine setting, supernatural sanctions (religion) must have played an important role in the consolidation of power in the hands of a nascent elite (Roscoe, in press).

#### 4.2. Initial Period

During the Initial Period, the size of monumental structures increases and the geographical ranges expands south to the Lurín Valley just south of Lima (12°15'S) and north to the Lambayeque Valley (6°30'S). Like the majority of Late Preceramic monumental sites in the North Central Coast valleys, Initial Period monuments throughout the entire range tend to be located inland from the shore. Seafood is still important, but agriculture plays an increasingly significant role in subsistence (see Burger, 1992; Moseley, 2001, for a review of Initial Period coastal sites). The suite of marine species exploited during the Initial Period is substantially similar to that of the Late Preceramic Period, with *Choromytilus* and *Mesodesma* among the most important mollusks and sardines and anchoveta dominating the fish (Sandweiss et al., 2001).

Monumental construction ceased or decreased greatly in the North Central Coast valleys after the Late Preceramic Period, and the Casma Valley (9°30'S) became the focal point for Initial Period development. Among the many Casma sites of this time, Sechin Alto was the largest mound in the Americas for its epoch; like Pampa de las Llamas/Moxeke, Sechin Alto and associated sites demonstrate large-scale site planning (Pozorski and Pozorski, 1987). At Pampa de las Llamas/Moxeke, this plan extends across 2 km, uniting a temple mound (Moxeke) with a monumental store-room (Pampa de las Llamas) along a central axis of symmetry (Pozorski and Pozorski, 1986, 1987).

A secondary focus of development occurred in the valleys around Lima (12°S), with sites such as Huaca la Florida (Patterson, 1985) and Garagay (Ravines et al., 1982) in the Rimac Valley, and a series of mound sites in the Lurín Valley (Burger, 1992). Burger's work at three of the Lurín centers, Cardal (Burger and Salazar-Burger, 1991), Mina Perdida (Burger, 1992), and Manchay Bajo (Burger, 2003), showed that these mounds were built incrementally. Burger and Salazar-Burger (1991) argue that the Lurín mounds would not have required sufficient labor and central direction to justify attributing the sites to a complex society. This view contrasts with the Pozorskis' (1986, 1987) interpretation of the Casma Initial Period sites as evidence for an early state. Given differences in the size and complexity of sites in the two valleys, social complexity may well have been unevenly distributed along the coast at this time.

Regardless of the level of social complexity in the different valleys of the Peruvian coast, people living in many of the valleys between about 6°S and 12°S built mounds during the Initial Period, continuing the tradition begun in the Late Preceramic Period. At the end of the Initial Period, the 3000-year sequence of coastal monument building came to a halt for at least several centuries at the same time that El Niño events increased in frequency (Sandweiss et al., 2001).

## 5. Conclusions

### 5.1. Summary

Drawing on the data reviewed in the preceding sections, we reconstruct the following sequence of El Niño frequency shifts and related cultural change on the Peruvian coast during the Holocene.

Before ca. 9000 cal yr BP, El Niño was present, but we do not know the frequency. People were fisher–hunter–gatherers living seasonally in small settlements such as Quebrada Jaguay.

Between ca. 9000–5800 cal yr BP, El Niño was absent or very low frequency. Fisher–hunter–gatherer lifeways continued with the addition of domesticated plants such as gourds (e.g., Erickson et al., 2005). Some settlements grew in size and may have been permanent villages such as Paloma.

Between ca. 5800–3000 cal yr BP, El Niño was present but at lower frequency than modern. Not long after the return of El Niño, people began building monumental structures on the Central and North Central Coasts. This mound-building tradition continued through this entire timespan, comprising the Late Preceramic and Initial Periods. Specific sites were built, used, and abandoned, and different valleys rose and fell in prominence, but viewed at the regional level, the tradition was unbroken.

After ca. 3000 cal yr BP, El Niño continued, but at frequencies within the modern range of variability. Shortly after this second climatic shift, the mound-building tradition stopped for hundreds of years.

### 5.2. Chronologies

Our chronology is built on remains found in, or in direct association with, archaeological sites. Because our ultimate goal is to help explain the cultural development of the study region, this approach gives us the most appropriate sequence. However, while the broad correlations between Mid-Holocene cultural and climatic change for the Peruvian coast are robust, we recognize that developing a detailed chronology is difficult given the multiple sources of error in age estimation from the various available archives. Most of the records we use depend on radiocarbon dating of both marine and terrestrial materials. Atmospheric  $^{14}\text{C}$  dates must be corrected for the variable radiocarbon production rate. Further, most of the archaeological dates available for the times and places of interest are bulk dates, with the potential to be biased by old wood (e.g., Kennett et al., 2002). However, a contextual review of the available archaeological dates does not indicate a notable old wood problem for the north coast of Peru – dates tend to be in stratigraphic order and consistent across sites with similar content. For marine dates, we face the additional uncertainty of determining the appropriate reservoir correction. With variation in upwelling through the Holocene, the magnitude of the reservoir must

have changed by centuries or more through time as well as through space. On-going work by Andrus and colleagues (2005) should provide a much more detailed picture of spatiotemporal change in the marine reservoir of Holocene coastal Peru.

Our chronology accords well with many natural proxy records throughout the region and the Pacific basin (see Section 3 in this chapter and other chapters in this volume). Most records indicate a period of greatly reduced interannual variability in the Pacific basin during parts of the Early and Mid-Holocene, followed by increasing interannual variability. However, not all agree with our exact timing or sequence. Laguna Pallcacocha in Ecuador (Rodbell et al., 1999; Moy et al., 2002), for instance, has an offset of approximately one to two millennia in the onset of El Niño and the later increase in ENSO frequency. At this time, we cannot say whether this discrepancy reflects a problem with chronology building or a real difference in the timing of change in the Ecuador highlands and coastal Peru. In general, global climatic change patterns have potential leads and lags from region to region; resolving those has to do with questions we are currently unable to resolve but which will be a focus of future research.

### **5.3. Climate and culture in Mid-Holocene Peru**

Over the last 30 years, we have accumulated evidence for two major climate transitions during the Holocene on the Peruvian coast. Each of these transitions also marks a notable change in coastal societies as expressed in their settlements, subsistence, the construction (or not) of monumental architecture, and social complexity. With such temporal conjunctures, it is tempting to go from collation to correlation to causation (Sandweiss and Quilter, in press). We can easily spin a plausible story about temples to control the new climatic variability introduced with the onset of El Niño, 3000 years of success while recurrence intervals were long (50 years to a century at least), and then a crisis of faith and temple abandonment when recurrence intervals became drastically shorter (probably less than 15 years). Nevertheless, such temptation is dangerous; as Sandweiss et al. wrote in 2001

Technology, history, cultural practices, religion, perception, and individual and group idiosyncrasies can all affect the way a society and its members respond to change. However, radical environmental change requires some response from the people who experience it.

In this chapter, we have reviewed the development of data on climatic and temporally associated cultural change during the Mid-Holocene on the Peruvian coast. We do believe that there is a relationship, though one of such complexity that it will be extraordinarily difficult to reconstruct in detail. In the final paragraphs, we point to the clearest conjunctures of climate and culture, as a guide to future research.

The most conclusive and temporally detailed evidence for a sharp climatic transition at ca. 5800 cal yr BP comes from a suite of dates on marine mollusks recovered *in situ* on paleobeaches by Perrier et al. (1994) and reproduced in Figure 2.4 (after

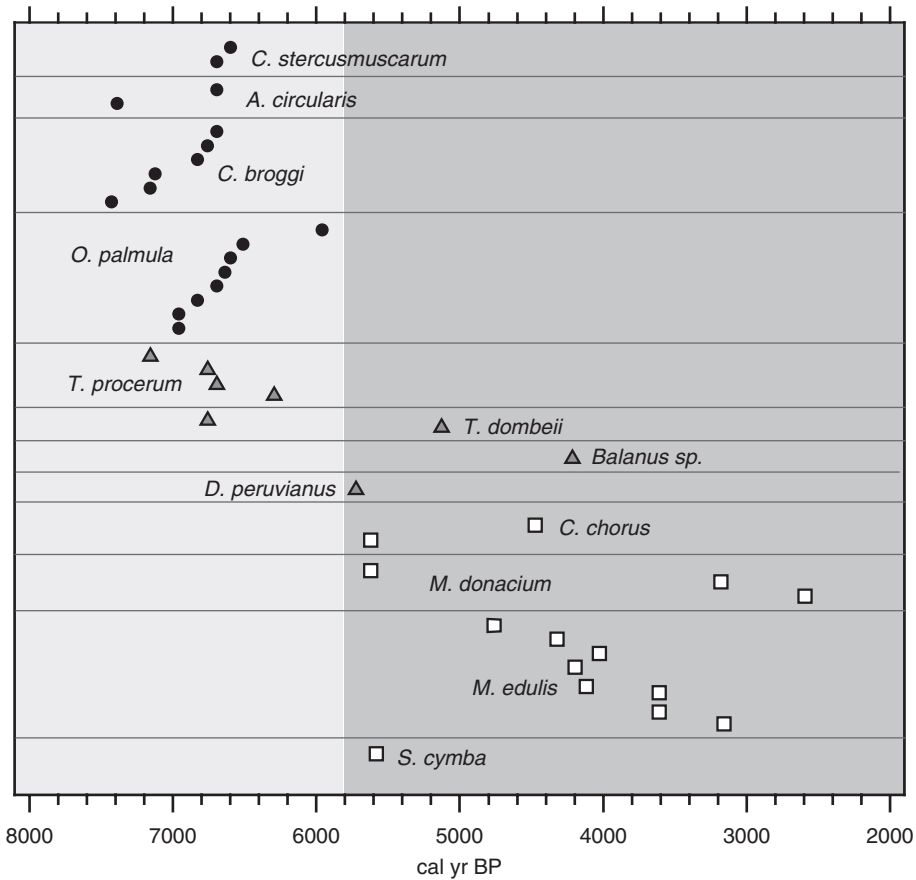


Figure 2.4. Dates on mollusks from the fossil bays at Santa and Salinas de Chao, northern Peru, arranged by water temperature requirements of the taxa. Circles are dates on species that can only tolerate warm-tropical water; triangles are dates on species that can live in both warm-tropical and warm-temperate water; and squares are species found exclusively in warm-temperate water. The difference in shading marks the postulated return of El Niño at 5800 cal yr BP. The data are from Perrier et al. (1994); the figure is after Andrus et al. (2003).

Andrus et al., 2003). All these dates should be subject to the same biases, so that even if the exact timing is offset, the direction and nature of the transition is obvious and well aligned with the less tightly constrained dates from archaeological materials (both marine and terrestrial).

The timing of change in the cultural record also fits this sequence but is less precise in chronological detail. Because early mounds tended to be built in multiple phases one on top of the other, and as yet few excavations have reached or dated the initial construction phases, it is still not possible to date the initiation of coastal temple building. The earliest dates for the use of temple mounds come from the test pits at several sites in the North Central coast valleys of Huaura, Supe, Pativilca,

and Fortaleza (11°10'S to 10°40'S) (Haas et al., 2004), which lack detailed context, from the final occupation at Los Morteros (Cárdenas 1979, 1995), and from Aspero (Feldman, 1985), where the earliest date is out of context and the stratigraphically coherent suite of later dates refers to the final two construction phases (ca. 4150–5300 cal yr BP). At this time, no known dates for monumental structures fall prior to the climatic transition at 5800 cal yr BP. However, dates late in the construction sequence at Aspero and Los Morteros fall within a few centuries of 5800 cal yr BP, as do some dates from the North Central Coast sites.

The collapse of the early mound-building tradition on the Peruvian coast after about 3000 cal yr BP is apparent in the absence of radiocarbon dates on temple mounds throughout the region during a several hundred year span following approximately 3000 cal yr BP. There is one exception, Manchay Bajo in the Lurin Valley, which lasted about 100 years longer than other sites. A massive wall was built at this site, not surrounding the site as would be expected for a defensive structure, but instead protecting the monument from El Niño-related debris flows coming out of two quebradas behind the site (Burger, 2003). At Manchay Bajo, the temple leaders thus appear to have invested in El Niño mitigation strategies (Sandweiss et al., 2001; Burger, 2003). This reminds us that mound-building may be linked to climatic change, but it is ultimately the result of human decision-making embedded in historical and cultural context.

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