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Human-Environment Interactions on the Desert South Coast, Peru: A Review of Paleoclimate Proxies and Archaeological Evidence

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Report

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Abstract

Human-Environment Interactions on the Desert South Coast, Peru: A Review of Paleoclimate Proxies and Archaeological Evidence

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The dynamic environment of the Peruvian Andes has always been conceptualized as central to human lifeways. A growing body of paleoclimate research provides new evidence to improve our understanding of the environmental processes that interact throughout this region. This has important archaeological implications to both generate new data on specific human-environment interactions, and more critically assess how the environment has influenced cultural transitions, and how humans have adapted and modified their surroundings. This report discusses existing paleoenvironmental proxy data for the desert Peruvian South Coast cultural region, and focuses on archaeological faunal assemblages, sediment cores, and geomorphological and sedimentological evidence. Each of these proxies differs in terms of scale, coherency, and temporal resolution. Combined, they provide evidence of long-term hyper-aridity in this region, influenced by El Niño Southern Oscillation (ENSO) fluctuations since the Late Pleistocene. ENSO has been the predominant climate driver for the Eastern Pacific, affecting coastal Peru to varying degrees on a multi-decadal scale since it onset at modern frequencies during the Middle Holocene. At local scales, geomorphological evidence and archaeological settlement pattern data suggest changes in precipitation, temperature, and climate variability, with specific relevance for human subsistence and resource access

within the coastal desert. This report also summarizes the development of sociopolitical complexity within the South Coast region, which played out within this sequence of environmental change and was closely linked to agricultural developments and marine resource access because past climates created fertile ecosystems within the desert and influenced ranges of marine food species.

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Introduction

This report compiles existing paleoclimate evidence for the South Coast region of Peru, evaluating several relevant proxies ranging from archaeological faunal data to marine sediment cores to understand how these reconstruct local and regional environmental conditions and climate fluctuations since the Late Pleistocene. The goal of this paper is to understand the proxy indicators and their temporal resolution to consider how, and the scale at which, global climate processes have affected the coastal landscape over the last 12,000 years. These factors have implications for integrating paleoclimatic evidence with archaeological data to consider questions of human-environment interactions and the trajectory of sociopolitical development. Correlation is not causation, and aligning climatic events is complicated by patchwork evidence and different error ranges.

The Peruvian coastline is distinctive both geographically and archaeologically as a culture region within the Central Andes. From sea level to the base of the Andes foothills at approximately 500 meters above sea level, this is arid desert maintained by the cold upwelling of the offshore Humboldt Current that minimizes atmospheric moisture accumulation, and a rain shadow enforced by the Andes. During the austral winter from May to November, there is dense fog cover. Annual rainfall averages around 0 mm in the form of a fog-like drizzle (*garua*), although local conditions can produce up to 30 mm of precipitation (Soßna, 2015: 50), and aridity decreases from southern to northern Peru with increasing proximity to the equator. River valleys originating in the Andes incise the desert plain, creating broad alluvial fans and fertile ecosystems for human lifeways. Besides wetland ecosystems, such as the mangroves in the northernmost Peruvian valleys, the only other wet zones are the seasonal, fog-sustained lomas vegetation environments. Modern efforts to map remaining lomas environments indicate they are primarily found in the northern and central portions of Peru. Together with soil conditions and differential preservation at archaeological sites, their range indicates that north of 12˚S has experienced moister conditions than south of this latitudinal boundary, although aridity has increased in the north since around 3000 BCE (Sandweiss et al., 2003:26). Archaeologically, the Andean coastline has been traditionally divided into the North, Central, and South Coast cultural macro-regions. The South Coast runs from the San Juan (Chincha) river drainage to the Loa River in Chile. Within Peru, this comprises the area from Chincha to the Yauca Valley.

The role of environment on human lifeways has been a consistent, and valid, theme in Andean archaeology over the course of the field's development for the past couple centuries. Increasingly, archaeological studies also highlight the widespread human modification of Andean environments (Contreras, 2010:243). The dramatic landscape appealed to geographers like Alexander von Humboldt, who explored the region in the early 19th century. Other early mapping and exploratory endeavors began to typify the Andean climatic regions in ways that emphasized the variety of vertical climatic zones stacked within relatively short distances along the altitudinal gradient of the Andes. These localized distinctions have been well known to local agriculturalists for millennia, and were formalized in academic circles by researchers like Tosi and Troll, using various geographic- or ethnographic-based typologies. In many cases, landscape classifications were based on which types of agricultural crops were currently cultivated there. For anthropology, these were fused with economic highland ethnographically-based models, most famously Murra's vertical archipelago, which was later expanded by geographer Stephen Brush into several specific types. For decades, the vertical archipelago model defined the conceptual nature of interaction and movement across the landscape in altitudinal patterns that might have been accurate in a specific local highland ethnographic context, but problematically did not extend to the non-mountainous coastal zones, which were seen as ethnogeographically uniform. The vertical archipelago model also linked culture and environment in a way that created a sense of timelessness and static for both Andean culture and climate in the highlands. The highland-centric approach to Andean cultural development was also intertwined with the archaeological focus on the Inca Empire, based out of the Central Highlands around Cusco. Additionally, some of the earliest paleoclimatic records produced for Peru relied on highland-based proxies, such as the Quelccaya ice cores (Thompson, 1985).

Increasingly, studies by archaeologists, geographers, geologists, and paleoclimatologists are generating paleoclimatic data to reconstruct the ancient environment across multiple zones of the Andes long before the Inca Empire. For coastal Peru, ENSO, or El Niño-Southern Oscillation, has been the primary regional climatic driver as a linked Pacific circulation phenomenon that operates within the lower atmosphere and upper ocean along the equatorial zone. For the past fifty years, ENSO has reoccurred every 3-7 years (Sandweiss, 2003:26). During severe El Niño events, the Peruvian coastline, and particularly the North and Central coasts, experience heavy rainfall that often leads to severe flooding and mudslides. The absence of the cold, nutrient-rich waters of the Humboldt Current is detrimental to the marine food chain. As a result, the strength and fluctuation frequency between El Niño and La Niña extremes "has always been an important factor in human-environment interactions in the Central Andes" (Soßna, 2015:36-37). Studies investigating the interplay between these ENSO-related drought and flood cycles and volcanism are particularly compelling for the coastal desert.

The wider availability of paleoclimatic evidence is complicated by the need to critically navigate the data to determine the applicability of geographically distant records, such as those between the highlands and the coast, in terms of climate conditions and correlating archaeological evidence. Even locally, records are complicated to apply. For example, Soßna (2015) recently evaluated climatic evidence for the Nasca-Palpa region in conjunction with settlement pattern research, providing a valuable comprehensive analysis of climate-culture links for the South Coast region, despite the Río Grande de Nasca drainage being situated farther inland than other South Coastal drainages such as Chincha and Pisco. Contreras's (2010) environmental archaeology review article offers a comprehensive summary of relevant environmental proxy studies for the Andes, classifying a decade of work in terms of structuring, modified, and sacred environmental perspectives. The primary Holocene paleoenvironment archives for the Andes region are lakebed and marine sediment cores, glacial ice cores, and archaeological fauna (254). From these, climate proxies are indirect measures of specific climatic conditions, since past conditions could not be directly recorded. Climate proxies from sediment and ice cores in the Andes include pollen, stratigraphy, dust, and δO18, which indicate aridity, water balance, vegetation and erosion (Contreras, 2010:255). Dendrochronology and corals have produced climate records in other regions of the world, but are limited for the Peruvian Andes. However, developing dendrochronological research in Argentina, Chile, and Bolivia suggests possible relevance of this proxy in the future for the Peruvian Andes (Boninsegna et al., 2005).

For the desert South Coast, lakebed and glacial cores from the highland Andes are of limited direct applicability, however coastal marine faunal remains have been particularly useful for reconstructing ESNO history. Therefore, this report focuses on marine and coastal sediment cores, archaeological fauna, geomorphological evidence of floods, and settlement patterns as climate proxies since the Terminal Pleistocene on the South Coast. Following the discussion of the proxy evidence, I summarize the established cultural chronology for the South Coast region as suggested by archaeological evidence from sites dating to from Terminal Pleistocene through the Inca period. To conclude, I present the evidence for marine and agricultural subsistence, and the overall increasing commitment to agricultural activities. Over the course of this sociopolitical trajectory, subsistence was a critical way in which populations interacted with the South Coast environment amidst climatic fluctuations.

Paleoclimate Proxies

Ice, Marine, and Terrestrial Cores

The Quelccaya ice cores, collected from the glacier's ice cap by Thomson et al. (1985, 2013), are arguably the best-known, and one of the first paleoclimate records for the Peruvian Andes applied in regional archaeology. Dust and oxygen isotope proxies offer a detailed interannual precipitation record for the southern highlands from 500 CE to the present. However, this 1500-year interval stops short of the previous millennium, which was a key period of developing sociopolitical complexity during which the Paracas and Nasca cultures emerged on the South Coast. The additional of later cores from the Nevado Huascaran and Sajama (Thompson, 2000; Thompson et al., 2003) extend the glacial ice record back to around 23,000 BCE, but these glaciers are distant from the desert coast. Originally, the Quelccaya record was invoked by archaeologists throughout the 1980's and 1990's to correlate highland precipitation patterns and coastal ENSO flooding, but additional research in both regions has portrayed a more complex relationship between these climatic processes between the regions. Although highland rainfall does affect water availability in the coastal river valleys, the glacial records do not provide direct paleoclimatic evidence, such as precipitation and temperature, for this region. However, evidence of highland conditions from the glacial record can corroborate more localized data because oxygen isotope values reflect eastern Pacific sea surface temperatures (SST's), despite the precipitation source of the Quelccaya ice being the tropical Atlantic (Thompson et al., 2013). For the South Coast, the most applicable cores are a marine core (Rein et al., 2005) and a lagoon core from the archaeological site of Pachacamac (Winsborough et al., 2012) which will be discussed in greater detail.

Rein et al. (2005, 2007) collected a high-resolution marine sediment core (106KL) from 80km off the central coast of Peru that provides comprehensive evidence for ENSO variability. The authors targeted interannual ENSO events by using sediment lithics and chlorin photosynthetic pigments as proxies to distinguish El Niño and La Niña, respectively. El Niño years are characterized by coastal rainfall, particularly in Northern Peru, so terrestrial eroded sediment lithics transported offshore by the Peru Current reflect continental flood events. Given the location of the core, the sediments probably primarily reflect input from the Rio Rimac in Lima. The authors reason that chlorin photosynthetic pigments indicate the low primary productivity that occurs offshore when upwelling ceases during El Niño events. Conversely, pigments increase with cooler La Niña events, while lithics decrease, isolating the proxy signals. The authors also used alkenones, synthesized by marine coccolithophoridae, which are abundant in warm, nutrient-poor waters, as a proxy for SST over the past 20,000 years. Combined, these three measures generate a record of suggested El Niño and La Niño intervals with accompanying SST's, over a timeline created by extrapolation between 45 radiocarbon dates.

ENSO is a shift in the Pacific Walker cell, or southern oscillation. This is a pattern of east-west tropical airflow driven by the oppositional atmospheric pressure force between the eastern and western Pacific. The Western Pacific around Northern Australia and Indonesia is a low-pressure zone, and the Eastern Pacific off the coast of

Peru is a high-pressure zone. Heat in the form of warm air and warm surface water, circulates East to West with the trade winds and Ekman wave transport, moving northwest along the coast of South America and then along the equator. Moisture accumulates over the warmer Western Pacific seas, then rises. As it dries and cools in the atmosphere, the air circulates eastward and sinks over the west coast of South America. Due to cold water upwelling, little moisture is contained over western South America, causing minimal rainfall along the arid desert coastline. The Andes themselves also contribute to the coastal desert conditions on the Pacific Coast because the mountains block moisture carried counterclockwise from the Amazon into the highlands by the Bolivian High pressure system.

ENSO is a natural interannual phenomenon, that causes significant interannual global climate variability (Carré et al., 2014:1045). During El Niño, the southeast trade winds regulating the Pacific thermocline weaken or change direction, causing a fluctuation in Walker Circulation known as *southern oscillation*. Coldwater upwelling weakens along the west coast of South America, deepening the thermocline and warming surface waters. Waters off Peru become nutrient-depleted as Kelvin waves reverse the movement of warm surface waters east to west across the tropical Pacific. As warmer, moist air accumulates over warmer seas off Peru, Australia and Indonesia experience cooler and drier conditions. Onshore, El Niño is characterized by significant flooding along the coast. La Niña is a fluctuation to the opposite effect, where South American seas are especially cool due to strengthened trade winds and high pressure systems that increase upwelling.

Rein et al.'s (2005) high-resolution core shows that El Niño onset around 17000 years ago (15) in the region, contemporaneous with Heinrich event 1 in the North Atlantic. SST's shifted several degrees higher at this time, within the range of modern average Eastern Pacific temperatures off Lima, Peru. ENSO activity strengthened significantly 12600 years ago, but weakened during the Middle Holocene from 8000 to 5600 years ago. The authors saw maximum coastal flooding occurred between around 1000-0 BCE. However, the record does not consistently show a converse relationship between biological productivity and lithic flux rate in the sediment record, as hypotheses suggest. For example, the Middle Holocene period of weakened El Niño displays both reduced lithic flux and reduced chlorin production. While there is no indication of large El Niño floods during this interval, the authors explain the low chlorin and carotenoid signal as "underestimated" due to erosion in this portion of the sediment core (7). Overall, this indicates that the converse relationship between proxies is a complex one.

Other El Niño evidence comes from coastal flood deposits (Keefer et al., 1998), faunal remains (Sandweiss et al., 2003), and oxygen isotope values collected from mollusks at coastal archaeological sites (Carré et al., 2014). These data will be discussed in later sections of this report. However, flood deposits at the sites of Quebrada Tacahuay and Quebrada de los Burros suggest ENSO activity at the Pleistocene-Holocene transition (Sandweiss et al. 2003:29-30; Keefer et al., 1998; Fontugne et al., 1999). The distribution of warm and cool water marine species in faunal assemblages at coastal archaeological sites from Middle Holocene archaeological sites suggests ENSO returned in after a 3000-year hiatus (Sandweiss et al., 2003). Around 1000 BCE, ENSO events increased in frequency to resemble modern ENSO conditions for this region (30). Isotopic data provides corroborating evidence that the modern ENSO regime onset between approximately 2500 and 1000 BCE (Carre et al., 2014). This was based on the variation frequency of cold and warm SST anomalies suggestive of El Niño and La Niña modes in the Eastern Pacific for the past 10,000 years. The study by Carre et al. (2014) also suggests ENSO variance was very low from 4000 to 5000 years ago, and tended towards cold El Niño events from 6700 to 7500 years ago.

Besides the marine core off the Central Coast, lagoon sediment cores from south of Lima offer a localized environmental record and paleo-tempestology sequence that could pertain to the broader South Coast region and correlate with the broader ENSO trends suggested by other studies. Unlike the marine core, the lagoon core contains evidence of seismic activity represented by mudslide, or *huaico*, deposits, which can also occur during severe El Niño floods. Winsborough et al. (2005) collected two sediment cores from the remains of the ancient Urpi Kocha Lagoon at the archaeological site of Pachacamac just south of Lima, Peru along the Lurín River on the Central Coast. Pachacamac was occupied from ca.350-1533 CE, and was arguably the most prominent coastal religious, oracular site by the Inca Period. The researchers sought to understand whether environmental conditions contributed to the cultural and religious significance of the site. The multiproxy analysis included pollen, diatoms, macrophytes, and archaeological remains from within both cores, and the authors argue for a lagoon ecosystem history of “successional dynamics” due to perturbations by isolated and overlapping ENSO-related flooding and tsunami events connected with seismic activity.

The cores record multiple flood events of both terrestrial (Lurín River floods) and marine (tsunami surges) origins, and this study shows how diatoms are a valuable proxy for flood sources by differentiating between freshwater, marine and brackish species deposited by different sources of water input.

Winsborough et al. dated the cores using 10 radiocarbon dates. One caveat of this record is that it is not fine-grained enough to discern and disentangle individual events and influences and particularly those occurring on different time scales. This chronological resolution also emphasizes high magnitude events, such as those that occurred simultaneously, to accentuate a signal in the record. For example, the researchers saw a mixed diatom assemblage between 156 and 194 cm within a thick flood deposit and argue that this suggests long-lasting El Niño conditions and a tsunami event (608). They argue that only the most intense ENSO-related storm surges reached the lagoon, where they saw thick sand deposits and corroborating diatom assemblages indicating 4 flood events (611). Together within the core record, these processes imply a compounded dramatic and disastrous environmental period of the type highlighted in collapse-focused archaeological and historical research. However, higher resolution evidence, or more radiocarbon dates, might separate these events chronologically and produce a more nuanced account of successive environmental influences, even if these environmental influences did compound in terms of their human impact. The authors documented four significant flood events at Pachacamac, which they speculate are combined El Niño and tsunami events: 398-277 BCE, 436 BCE-93 CE, 260-283 CE and 436-651 CE, 995-1008 CE. The last of these from 995-1008 CE they attribute to the

Naymlap flood, which occurred around 1100 CE and was documented in the Moche Valley (611).

Overall, ENSO proxies for the Peruvian coast include δO18 values from shells, chlorin pigments, lithic facies, the sedimentary record, diatoms, and faunal remains. ENSO evidence from marine cores suggests the strongest El Niño floods occurred on the Peruvian Coast over the past 15,000 years (Rein et al., 2005), and isotopic evidence shows that ENSO variability has been higher in the last century than in any other period of the Holocene (Carré et al., 2014:1046). The core records are more continuous paleoclimatic archives than faunal remains, and generally, geomorphological records, which can be eroded away for certain periods. The Lima marine core provides a generalized SST record for the Peruvian coastline, while the localized record at Pachacamac reconstructs a specific micro-environmental record. The Pachacamac core is also detailed enough to capture human inputs into the system. Diatoms, algae, and microcharcoal indicate that the area was intensely irrigated by the residents at the site of Pachacamac. Both cores, but especially the marine core, address the ENSO paleoclimatic record by incorporating both continental and marine environmental processes and conditions, using proxies to determine continental flooding, or reconstruct SST's, as both are distinctive characteristics of ENSO events.

Geomorphological Evidence

The geomorphological record on the Peruvian coast contains remnants of ENSO flood events, as well as marine tsunami inputs, as already mentioned. A series of studies have employed geomorphological surveys within the South Coast Region to investigate specific ENSO events and catastrophic floods and tsunamis (Magilligan and Goldstein, 2001; Spiske et al., 2013; Zaro et al., 2013), differentiate El Niño and La Niña events (Magilligan et al., 2008), compile long-term El Niño trends (Fontugne et al., 1999), and determine landscape change (Beresford-Jones et al., 2009; Beresford-Jones, Lewis, and Boreham, 2009). Methods include coring, test pitting, and reconnaissance to describe and collect sediments. Sediment analyses are often used with complementary analyses like pollen, and botanical evidence, especially to do intra-valley environmental reconstructions and incorporate archaeological data to describe human use of the landscape.

Numerous studies have been carried out in the Ica and Moquegua valleys to understand valley transformation by both human and natural processes. This has powerful implications not only in terms of reconstructing flood event chronologies, but also for considering the longer trajectory of agricultural impacts on the desert landscape. For example, in Ica, Beresford-Jones, Lewis, and Boreham (2009) carried out geomorphological survey in conjunction with survey pits along an East-West transect of the Samaca Basin. They described sediment and soil sequences that show the long-term erosional processes as well as alluvial and aeolian deposition. The sediment analyses allowed them to identify four distinguishable geomorphic units through the floodplain and determine the path of incision as the river channel gradually narrowed and deepened within the Samaca Basin to its contemporary level. Sediments also directly indicated the occurrence of high energy flood events across the floodplain.

Notably, the authors discovered alluvial sediments covering buried agricultural soils on relict terraces in what is today a desert landscape meters above and half a kilometer from the current Rio Ica floodplain. Test pitting in these relict terraces produced complimentary data, including archaeological materials showing that humans had cultivated these areas when the floodplain was higher and wider. Botanical evidence showed that the inhabited area was also once covered in *Prosopis*-dominated riparian dry forest during the Early Intermediate Period (250 BCE-650 CE) on the South Coast. The authors posit that a mega flood at the end of the Early Intermediate Period, together with human-induced erosion by deforestation, caused river incision. Agriculture was subsequently abandoned with the floodplain alteration. The flood and the human effects occurred on different scales, and compounded to "breach critical desert geomorphic thresholds" (14). Future hypothesis-driven research can investigate whether other valley landscapes in the South Coast were also wooded during agricultural expansion through the Early Intermediate Period with the rise of the Nasca cultural tradition. Woodlands may have facilitated shifts in regional subsistence strategies and sociopolitical complexity by maintaining crucial zones of arable land throughout the region.

In the Moquegua Valley, Magilligan and Goldstein (2008) used geomorphology to investigate ENSO frequency and magnitude by creating a chronology of flood events, reported in calibrated years BP, for the past 20,000 years. The geomorphological differences of the valley itself allowed the researchers to distinguish between El Niño and La Niña flood events because recent events demonstrate that mid-valley tributaries flood only during El Niño events, in comparison to the mainstem, that floods during both El

Niño and La Niña periods. Overall, the sedimentary evidence shows strong variation in both flood occurrence and strength over the past 20,000 years in this valley. Large El Niño floods did not occur prior to 5,600 years ago, and there was an overall intensification in Rio Moquegua flooding for the last 2,000 years. A large debris flow indicated a catastrophic flood around 2250 BCE (4200 cal yr BP), and other sediments suggest a regional El Niño occurred around 150 BCE (2100 cal yr BP). There is evidence that Mega Niños caused floods in 3640 BCE (5590 cal yr BP), 170 BCE (2120 cal yr BP), 730 CE (1220 cal yr BP), and 1550 CE (400 cal yr BP), with evidence for the well-known Miraflores flood event seen throughout the South Coast and caused by a strong El Nino in the mid fourteenth century CE. However, the authors suggest that their evidence of flood events may be limited to only larger floods, and thus, stronger El Niños. This is because flooding observed during the 1997 El Niño, which was classified as a particularly strong ENSO event, produced only minimal sedimentological remains in the Moquegua tributary channels.

Fontugne et al. (1999) also argue that fewer El Niño events occurred during the Middle Holocene. They studied sediment sequences in the far south of Peru at the Quebrada de los Burros to document human occupation in relation to ENSO activities. They dated 10 organic-rich buried wetland deposits alternating with eolian sand deposits that represent millennia of low-energy deposition. Overall, this area was dry during the Middle Holocene, punctuated by shorter intervals of moist soils development between approximately 6100 and 1430 BCE (8060-3380 cal yr BP). Archaeological artifacts indicate permanent water availability for occupation during these moist intervals.

However, the authors argue that ENSO-induced precipitation did not facilitate these moister conditions because there was little evidence of ancient, high-energy debris flows comparable to those observed during recent El Niño events in the Quebrada. They did document *huaico* mud-flow deposits probably representing strong El Niño events at 7030 BCE (8980 cal yr BP), between 3440 and 2600 BCE (5390 and 4555 yr BP), and after 1400 BCE (3380 cal yr BP) that seem to align with El Niño deposits identified at Quebrada Tacahuay by Keefer (1998) (176). Instead, they propose that during the Middle Holocene, more extensive coastal fogs produced by enhanced upwelling provided a regional moisture source during a period of fewer El Niño events.

While sediments offer direct evidence of flood events to suggest ENSO climatic conditions both locally and regionally, there are some limitations to using this data for flood reconstruction. Not all floods are visible in the geological record, because some deposits have been eroded by later processes or are unexposed. For example, the Peruvian coastline should have millennia of historical tsunami deposits given the regularity of these events, but a recent survey found that tsunami deposits, which are much thinner than ENSO flood deposits, are poorly preserved (Spiske et al., 2013). Dating flood deposits also depends on radiocarbon dating (which is subject to reservoir effect) and optically-stimulated thermoluminescence (OSL), which have their own caveats and ranges of error. OSL can be applied to recent sediments but also covers a wider time span than radiocarbon dating. Some studies (e.g. Manners et al., 2007) also incorporate data and models formulated based on modern floods, which provide valuable comparative data for interpreting the past record, and particularly for understanding the strength of ENSO events. Deposited sediments are also valuable records because they comprise both physical processes and human activities to show how each affected landscape and to document long-term landscape change in the river valleys occupied by human populations. With the addition of future data, researchers can continue to correlate dated flood events between valleys to reconstruct the regional terrestrial ENSO impact history.

ARCHAEOLOGICAL MARINE FAUNAL ASSEMBLAGES

Hyperarid coastal desert conditions are optimal to preserve organic botanical and faunal remains, including marine mollusk shells and fish bones. Through the Terminal Pleistocene and Early to Middle Holocene, residents at many South Coast sites collected mussels and limpets from rocky intertidal zones, mussels and snails from the rocky subtidal zone, clams and mussels from the sandy intertidal zones, and scallops from the ocean floor (Sandweiss et al., 1989:66). Subsequently, these faunal assemblages from Peruvian archaeological sites provide an additional ecological proxy for Pacific sea SST and ENSO. These remains were usually collected as food sources by ancient coastal populations, and can be found buried or on the surface in large midden deposits and sometimes burned from roasting. Others are recovered from sites in the form of utilitarian artifacts like beads and fishing net weights because mollusks were utilized as raw material for making objects. If the recovered mollusks are original deposits and there was no mass transport, the species at a site can reflect a set of required localized marine conditions for the time period that the species were available and utilized.

However, the faunal assemblage reflects both an original resource base and human resource use that can be difficult to distinguish (Reitz and Sandweiss, 2001). As a proxy, archaeological fauna is “fundamentally useful”, but problematic because fauna are anthropogenic deposits that need to be considered as the result of human activities in terms of their presence, preservation, and sampling (Sandweiss, 2003:24). When sites are occupied, humans select species from their surroundings, transport some to the site, and then make processing and deposition decisions. Later, archaeologists select where to excavate, what to collect, which of the preserved remains to analyze. The faunal data assemblage is subsequently the result of these cumulative research decisions and stages (Sandweiss, 2003:24).

Sandweiss (2003) argues that for interpreting faunal assemblages, species presence is more important that absence, because people never collect everything available from their surroundings (24). Coastal assemblages generally include barnacles (*Balanus* spp.), fish, crabs, sea urchins, and studies rely on the abundances of specific warm- and cold-adapted bivalve species—and knowledge of their current geographic ranges—to infer nearshore oceanic conditions. These can then be extrapolated to reconstruct SST anomalies associated with ENSO patterns. Sandweiss et al. (1989) provide a useful table organizing typical coastal mollusk species, specifically those found at the Ring Site, according to their marine habitats (66).

For paleoclimatic reconstruction, typical warm-adapted species include *Anadara tuberculosa* and *A. grandis*, as well as *Ostrea megadon*. Cool-adapted species include the chiton *Enoplochiton niger*, and the bivalves *Choromytilus chorus*, and *Mesodesma* *donacium*, among others. *C. chorus* and *M. donacium* are the primary indicators of ENSO events because these Peru Current species are especially sensitive to warm temperatures, and populations do not recover quickly following mortality events. Modern anecdotal evidence and experimental results show that C. chorus experiences mass mortality under severe El Niño events where oceanic temperatures can be over 28˚C for 12-18 months (Sandweiss et al., 2001). The range of *M. donacium* was pushed south of 15˚C by the 1982-1983 El Niño event, and even farther south by the El Niño in 1997-1998 (Sandweiss et al., 2001:604). *D. obesulus* has wide temperature tolerance and quicker population recovery during strong El Niños. Faunal-based paleoclimatic reconstruction assumes these species were constrained by similar conditions in the past.

Sandweiss et al. (2003) review the climate conditions indicated by archaeological faunal remains from Peruvian coastal sites from the Terminal Pleistocene (11,000-9000 BCE) through the Middle Holocene (7000-1000 BCE). The faunal assemblages from the majority of southern sites are composed of endemic cold-water mollusk species of the Peru Current, indicating similar oceanic conditions as today. The faunal data from these archaeological sites provides additional support of a critical shifting disjunction in oceanic temperatures at approximately 12˚S along the Peruvian coast (Sandweiss et al., 2003:34). Since the Middle Holocene, sites south of 12˚S, including Paloma, Quebrada Jaguay, the Ring Site, Quebrada Tacahuay, and Quebrada de los Burros contain cool-adapted mollusk species typical of the modern conditions, whereas the northern coast supports warm-water species. Prior to around 3800 BCE (5800 cal BP), the divide between longstanding arid conditions and cool SST's to the south and more temperate conditions to the north was probably closer to 10˚ S because species found at Middle Holocene sites located between 10˚S and 12˚S are cool-adapted to temperate. After 3800 BCE, cool-water species like *M. donacium* and *C. chorus* were still found in archaeological assemblages from North Coast sites as far north as 7˚S, but disappeared by around 850 BCE as the proportion of more temperature-tolerant *D. obesulus* increased. This distinction is important to show that paleoclimatic conditions are not uniform along the Peruvian coastline, and it indicates that the South Coast has been a hyperarid desert climate for a very long time in contrast to the North Coast.

One of the most important climatic records relevant to human history in Peru to come from faunal data is the indication of ENSO onset, or a significant increase in frequency, in the Middle Holocene. The faunal evidence records cooler mean annual SST's, and in conjunction, less seasonal precipitation on the North Coast, beginning around 3800 BCE, which has already been described as a key climatic shift. The faunal evidence does not directly indicate the frequency of ENSO fluctuation for this shift, but because the cooler conditions reflect those of present day, we can infer that ENSO increased in frequency both at 3800 BCE, and again around 1000 BCE (Sandweiss et al., 2003:30). At the site of Siches in Northern Peru, which was occupied through the transition at 3800 BCE, warm water mollusks dominate faunal assemblages from around 7000-3800 BCE (9000-5800 cal BP), suggesting that ENSO did not operate as it does today. However, the assemblage becomes mixed, and eventually dominated by temperate and cool-adapted water species in subsequent occupation phases (Sandweiss et al., 2003:31). Data from other Middle Holocene sites at Quebrada Chorrillos, Avic, Ostra, Salinas de Chao, Almejas, Huaynuná, the Huarmey Valley, and at Aspero and Caral in the Supe Valley confirm this finding (Sandweiss et al., 2003; Reitz and Sandweiss, 2001).

Cold-water species *M. donacium* and *C. chorus* disappear from faunal collections from northern Peruvian sites between 7˚S and 9˚S around 1250 BCE (3200 cal BP), indicating the second Holocene ENSO frequency change. Assemblages from sites in the Casma and Moche Valleys and the Salinas de Chao contained greater amounts of *Donax obesulus*, which tolerates a higher range of temperatures than either *M. donacium* or *C. chorus* (Sandweiss et al., 2003:33-34). This faunal shift indicates that offshore coastal upwelling of cold waters was reduced, warming SST as is typical during El Niño events. Sandweiss et al. (2003) note that the date of increased El Niño activities coincides with some cultural transitions, specifically temple abandonment on the Central Coast and North Coast, concluding cautiously that the aligned data "certainly suggests a role for climate in these cultural developments" (34). Sandweiss et al. (2001) cite additional Pacific paleoclimate records, including rising lake levels in northern Chile and at Lake Titicaca, and a Chilean marine paleoclimate record that support this date for a frequency shift to modern conditions (604). Additional records from the western Pacific, and modeling studies provide additional evidence (605).

While mollusk taxa are a proxy for regional and local oceanic conditions, additional analyses of the shells themselves have the potential to resolve climate shifts at finer temporal scales. For example, growth banding on the mollusk shells can indicate seasonal climate variation, and Sandweiss et al. (1989) note alternating light-dark banding on *M. donacium* shells from the Ring Site (62). Research by Carré et al. (2014) used isotopes measured within fossil *M. donacium* shells to reconstruct Eastern Pacific ENSO spatial patterns and amplitude on a monthly scale. They used measured δO18 values as a proxy for SST, which allowed them to spatially map ENSO anomalies in this region. A total of 180 samples were gathered from 7 coastal midden sites in Peru, as analyses require a bulk sample comprising multiple mollusk specimens (similar to foraminifera) (Carré et al., 2014:1045). As a proxy for SST, *M. donacium* bivalves, much like corals, usefully record SST seasonality on a monthly scale in the surf zone of beaches.

Overall, faunal evidence is most valuable for detecting large-scale changes in ocean conditions along the Peruvian coast, and shows the applicability of archaeological data to paleoclimate work. While changing SST suggests large-scale ENSO frequency patterns, corroborating, high-resolution evidence is needed to determine the occurrence of specific ENSO events. Additionally, since faunal evidence is associated with archaeological sites, there are geographic gaps in the record for the Early and Middle Holocene periods, and the data is limited to excavated sites. That scarcity of sites from this period means that comparing warm and cool-water adapted species yields a patchy and somewhat low-resolution reconstruction of SST along the Peruvian Coast. Faunal data also require more precise dating to improve the accuracy of this timeline of temperature changes. Many of the sites summarized by Sandweiss et al. (2003) have large dating ranges on the order of several thousand years, permitting only a rough ordering of general SST changes from the Late Pleistocene through the Holocene. While this work has bracketed major shifts in ocean conditions through the Holocene, additional analyses and dates from these sites would help resolve these events on finer time scales.

Terrestrial Fauna

As with mollusks, archaeologists have utilized terrestrial faunal assemblages to investigate localized environmental condition around sites of human occupation. For the desert South Coast, terrestrial fauna, and especially snails, have been used to distinguish the moist, seasonal, vegetation ecosystems known as lomas that attracted both humans and fauna within the desert. Lomas vegetation, which is predominantly *Tillandsia*, relies exclusively on fog that condenses in the Andean foothills during the austral winter. Lomas are relatively rare and fragile ecosystems on the South Coast today, but archaeological investigations find evidence of lomas because, like marine mollusks, land snails were collected and consumed at occupation sites. Therefore, they have similar proxy limitations to the mollusks found in archaeological contexts. Land snails may have been preferable only in certain periods, such as when marine resources were scarce, such as during ENSO events (Beresford-Jones et al., 2015:206). Sandweiss et al. (1989) report that Southern Peru coastal lomas expanded during the strong 1982-1983 El Niño, which suggests prehistoric populations would have depended more heavily on lomas ecosystems as fish and mollusk populations declined during ENSO fluctuations. Land snails are proxies for both local and possibly broader scale climatic events like El Niño events because wetter conditions expand lomas vegetation growth, which provides habitat for snails like *Scutalus* as well as other organisms including insects, lizards, rodents, birds and large mammals like deer, puma, and guanaco (Beresford-Jones et al., 2015:208). In the Ica Valley, the most common snail species was *Boxtryx reensi*, which graze on the lomas during the winter growing season (206).

At the Ring Site, Sandweiss et al. (1989) found high concentrations of *Scutalus* in the lower stratigraphy of excavated archaeological units and suggests the snails were deposited during a time of lower sea level and/or high intensity ENSO events. However, the abundance of snails could also be due to the wetter Early Holocene conditions in the Ilo area, which is suggested from independent sources. Beresford-Jones et al. (2015) used snail shells as proxy indicators of ancient lomas between the Pisco and Acarí river valleys to argue that local scale, moist lomas existed during the Middle Holocene and Peruvian Preceramic Period from approximately 6000-2500 BCE. Additionally, the discovery of processed snail shells in middens alongside evidence of butchered guanaco remains indicates that humans utilized lomas ecosystems as part of diverse subsistence and resource strategies. Beresford-Jones (2015) correlates these archaeological sites (and by extension extensive lomas environments) with Carre's (2014) oxygen isotope records to conclude that seas were colder for several hundred years during this period. The implication is that this diverse hunting and gathering lifestyle declined as SST's warmed around 2500 BCE (212).

Overall, terrestrial faunal remains are a similar type of proxy as mollusk remains because they directly indicate, and are the result of, human subsistence and resource dependence. However, fauna indicate local terrestrial moisture, rather than regional oceanic temperatures. Comparisons between the ratios of consumed terrestrial versus marine fauna from sites might reflect subsistence shifts due to offshore conditions altered by ENSO fluctuations, but this would be challenging to elucidate given the many factors affecting the assemblage. As seen with the climatic conditions implied by lomas ecology, terrestrial fauna can ultimately corroborate other records to address SST and ENSO frequency on a broader scale.

Settlement Patterns

Environmental conditions influence human settlement patterns (Sandweiss 2003:24), particularly in desert environments where water sources are limited. As mentioned previously, permanent coastal settlement locations have generally correlated with rivers, streams, lomas, wetlands, and groundwater seeps in the hyperarid deserts. Therefore, sites typically signify water sources, while site absence during certain periods could be attributed to decreased water availability, including changes to precipitation regimes that support lomas environments. For example, Beresford-Jones et al.'s (2015) analysis of sites showed close correlations between water resources and Middle Holocene site locations: Amara Norte I, La Yerba II, and Abra Sur de Amara I were situated in lomas, and La Yerba II was adjacent to the Río Ica estuary. Several Late Pleistocene/Early Holocene sites are exceptions. For example, the Terminal Pleistocene site, Quebrada Jaguay, was probably occupied only part of the year, since modern springs are over 5 kilometers from the site, and the stream flows in the Quebrada today for a maximum of several weeks (Sandweiss et al., 2003:29). At the time of occupation, this was the only site in the region, however the settlement pattern expanded around the Quebrada in the Early Holocene, probably during a time of increased winter fog that would have provided moisture (29).

Sandweiss et al. (2003) use settlement pattern data to infer precipitation patterns and cautiously suggest that South Coast spring-fed sites were continuously occupied through the Middle Holocene. By contrast, there were no sites throughout this region that depended solely on precipitation or seasonal rivers. However, it is still difficult to determine exact precipitation levels, and the authors note it is unclear whether there are correlations between ENSO events and settlement patterns, which are also directly correlated to precipitation (37). Soßna's (2015) detailed settlement analysis for the Nasca-Palpa region, is discussed more in the conclusion of this report. However, he also found it challenging to correlate settlement pattern data for the Río Grande de Nasca drainage directly with broader climatic events like ENSO fluctuations. Settlement patterns did correlate with resource access, and access to multiple resource zones, however, providing additional support for the idea that settlement patterns can be used to indirectly infer local paleoenvironment conditions.

Another factor affecting coastal settlement, and our knowledge of coastal sites, was that sea levels were lower from the Terminal Pleistocene through the early Holocene. The northern coast of Peru has a wider coastal shelf than in the south, therefore more early shoreline sites would be obscured in the north (Sandweiss et al., 2003). Early sites like the Ring Site, presently located .75 km inland, would have had shifting shorelines during occupation because sea level was rising until approximately 3000 BCE (Sandweiss et al., 1989:64). Sandweiss et al. (1989) explain that rather than supporting a rapid coastal uplift hypothesis in the Ilo area in the far south of Peru, Ring Site data show that the land was relatively stable. Instead, eustatic sea level rise drove an encroaching shoreline closer to the site from the time of its initial occupation between 8,000 and 6000 BCE, and sea level stabilization around 3,000 BP (70). The authors argue that the abundance of heavy marine shells versus easier-to-carry fish, marine birds and mammals, as well as the distributions of the lomas *Scutalus* landsnails in the levels of the archaeological excavations support this model of a nearing coastline (71).

Lifeways and Sociopolitical Development on the South Coast

As discussed, evidence suggests the South Coast has been a hyperarid desert since long before human occupation (Sandweiss et al., 2003). Coastal settlement has always correlated directly with freshwater access because water is necessary for subsistence and survival in this environment. Contreras (2010) reasons that water's importance on the Coast may have been one of the reasons archaeologists began considering ecological impacts on human lifeways in the Andes (247).

The coastal desert has been occupied since the Late Pleistocene/Early Holocene. Early settlements like Paijan, Amotape, Quebrada Jaguay, the Ring Site, and Quebrada Tacahuay consisted of shell middens and house structures positioned to exploit streams. In the Quebrada de los Burros, Fontugne et al. (1999) found human occupation from around 7690-1430 BCE (9640-3380 cal yr BP) was associated with wetlands (173). In some cases, such as at Mastodonte, site locations indicate previously active river channels, and some sites may have been seasonal camps, rather than permanent occupations. Fishing and marine resources were exploited early, and hunter-gatherers also utilized lomas environments and wetlands where they could access abundant resources (Beresford-Jones et al., 2015). Our understanding of coastal sites is limited by gaps in the record for stretches of coastline, but the climate in the northern part of Peru was wetter, with warmer SST's than present day in contrast to the South Coast, where SST's were probably at modern values and possibly higher seasonal flow from the highland river valleys (Sandweiss et al., 2003:30). During this period, there was probably seasonal precipitation, and ENSO activity was reduced. North of 10˚S, SST's were 3-4˚ warmer than modern temperatures (Sandweiss et al., 2003:37).

As already discussed, key climatic changes occurred around 3800 BCE, when ENSO frequency increased, and again around 1000 BCE, when modern climatic conditions were established (Sandweiss et al., 2003:2001). For the North Central coast (6-12˚S) Sandweiss et al. 2001 suggest possible temporal connections between ENSO events and the rise and fall of large monumental political-religious sites, like Aspero, Garagay, and Mina Perdida during the Late Preceramic and Initial Period. Many of these sites were constructed around 3800 BCE, and collapsed by around 850 BCE, at least a hundred years after the second shift in ENSO frequency probably occurred. Evidence from several long-term coastal occupations like Jaguay and the Ring Site indicate that coastal residents had developed multiple fishing technologies (Reitz et al., 2016) to sustain marine subsistence strategies even with these climate changes into the Holocene Period.

While cultures of the North Coast were constructing monumental architecture, South Coast sites were likely independent villages that interacted through exchange

(Soßna, 2015:63). Silverman uses the lack of a monumental architectural tradition to distinguish the South Coast from the shared interaction sphere of coastal cultures to the north, who probably had larger population sizes during the Initial Period and are presumed to have been agricultural societies by this time (119). Initial Period (1500-800 BCE) South Coast sites include Disco Verde, Hacha, Pernil Alto, Erizo, Mastodonte, and these are mostly domestic sites or shallow middens. Many, like Disco Verde and Puerto Nuevo were situated to exploit both freshwater and marine environments. For example, Puerto Nuevo accessed "a large zone of economically important swamps and marshes" that formed due to runoff from the Pisco River and the high water table" (Silverman, 1996:115). Silverman (1996) argues that existing water sources, like river valleys and springs (115), rather than irrigation, for food crop cultivation during this time. She also stresses the significance of Quispisisa obsidian and suggests that the Pisco-Paracas region came to have a "particularly privileged role" in a southern Peru interaction sphere due to the Pisco Valley's access to the highlands, and the easy access to marine resources on the Paracas Peninsula (119).

Paracas emerged during the Early Horizon Period (800-250 BCE) following a debated period of Chavín stylistic influence on the South Coast. Despite some stylistic similarities between early Paracas and Cupisnique/Chavín, the Early Horizon Period "clearly developed out of local Initial Period predecessors", as many Initial Period sites remained occupied (Soßna, 2015:63). Silverman (1996) attributes the rise of social complexity on the South Coast to concurrent factors and influences that consolidated and promoted elite power (122-123). One of these, she argues, was climate change in the

Central Andes that resulted in population movement, pressure, and conflict to promote the emergence of elites (123). Population also grew on the South Coast, possibly in conjunction with increasing commitments to maize agriculture, which has been documented at earlier Initial Period sites. It should be noted that the Nasca culture used maize extensively by the early centuries AD (123).

The Paracas culture was centered around the Paracas Peninsula and Pisco Valley, but associated sites have been found as far north as the Cañete Valley. The culture was highlighted by Julio Tello's excavations at Arena Blanca and Wari Kayan on the Paracas Peninsula that revealed hundreds of elite mummies. Tello distinguished two sequential Paracas phases based on burial styles, but Cavernas and Necropolis are now thought to both be later Paracas phases. While the elite Paracas Peninsula sites have been the focus, early Paracas village occupations are known at Puerto Nuevo east of the peninsula, Mollake Chico, Karwas, and Jaurango. The inland site of Cerillos, excavated by Wallace (1962), had a possible temple structure, and "may mark the beginning of a development towards a more pronounced social complexity" (Soßna, 2015:65).

Soßna's (2015) surveys of the Nasca/Palpa region found that inland settlement dramatically expanded throughout the upper valley headlands over the course of the Paracas period, and especially during the Middle Paracas Phase (163). Fortifications also increased and there was an overall trend toward larger settlement sizes. Settlement in some of the narrow upper valleys of the Nasca area may have been facilitated by the return of more stable climate conditions around 450 BCE that helped rain-fed agriculture (160). For this specific area of the South Coast, the majority of the lower valley floodplain sites appeared during the Late Paracas phase from 380-260 BCE, and small-scale irrigation must have used for cultivation because of the impossibility of rain-fed agriculture below 1000 meters above sea level (171). Soßna suggests that cotton may have gained importance as a crop in these areas, based on the abundance and quality of Paracas textile artworks associated with this period (173).

In later Paracas phases, the number and size of Paracas sites expanded across the Ica, Pisco, and Chincha lower valleys as well. Some of these sites were monumental adobe mounds and *huaca* complexes, including Huaca Soto, Huaca Alvarado, San Pablo, and La Cumbe in Chincha, and Animas Vajas and Animas Altas in Ica (Canziani, 1992; Silverman, 1996:128-9). Together with differential burial patterns, they suggest a social hierarchy and an increase in socio-political complexity, however there is no indication of "a formal multi-valley political entity" (Soßna, 2015:66). Settlements included the site of Chongos in Pisco and Wari Kayan, Chuchio, and Karwas on and around the Paracas Peninsula (Soßna, 2015:66). In Pisco, Paracas settlement locations are associated with wetland habitats (Peters, 2013). Silverman (1996) notes that the location of sites around the middle valley neck in Chincha indicates that settlements were taking advantage of water for irrigation agriculture, which was well underway by this period alongside continued reliance on marine resources.

In the Chincha Valley, recent archaeological research at the ceremonial mound of Cerro del Gentil and the El Mono mound complex on upper edge of the lower valley provides evidence of possible interaction between the coast and highlands (Stanish et al., 2014; Tantaleán et al., 2013; Tantaleán, 2016). The Chincha Valley's highly-visible monumental buildings of the Late Paracas phase "were points of arrival, meeting, and departure" for regional social groups (Tantaleán, 2016:479), and were constructed along with canals, paths, and geoglyphs, as part of a ritual and political landscape, probably under an organized project by Paracas elites (494). At Cerro del Gentil specifically, astrologically-aligned geoglyph lines made from rock clusters extend across the desert plain, connecting the sites with presumed paths toward the highlands that may have been involved in ritual behavior as well as economic interaction (Stanish et al., 2014). The first geoglyphs in Palpa date to the late Paracas period and depict anthropomorphic beings, in what Soßna (2015) describes as a transition from petroglyph depiction of ideas (66-7).

The cultural transitions that occurred in the Late Paracas Period in the final centuries BC are not well understood. Based on his settlement analysis for the Nasca Palpa region, Soßna (2015) suggests that large-scale highland migration occurred during the Late Paracas phase, with a replacement scenario of highland settlers leaving the region while other coastal valley residents moved into the foothills (175). In the Early Intermediate Period (250 BCE-650 CE), the Topará and Nasca regional cultural traditions emerged as the predominant regional cultures. Topará, first defined based on a ceramic style analyzed at the site of Jahuay at the Quebrada Topará, seems to have been centered in the northern portion of the South Coast from the Cañete to Pisco Valleys. Topará sites and occupations are known at Chongos, Pachinga, and Dos Palmas in Pisco, Cabezas Largas on the Paracas Peninsula, and Pampa de Gentil in Chincha (Soßna, 2015:67), although Topará ceramics have been excavated at multiple sites, including in the Chincha Valley, and suggest contact with Nasca. The origins of Topará are unclear, but it is generally considered either an extension of Paracas Necropolis culture or a distinct group that arose in the northern part of the South Coast (Proulx, 2008:569), rather than regional invaders from the north. Soßna (2015) describes Topará as “a purely social and cultural development” with no obvious correlations to climate change in the Nasca-Palpa region (267). Proulx (2008) argues that the more centralized Topará culture replaced Paracas Necropolis in Pisco and on the Paracas Peninsula over the course of the Early Horizon, “coexisting with and influencing both” Paracas Necropolis and Nasca 1 phases (569).

Nasca was probably a stratified, multi-valley polity centered in the Río Grande drainage and extending to the Ica Valley in the southern half of the South Coast, and the monumental site Cahuachi developed into a pilgrimage center by 200 CE (Soßna, 2015:67). Important Nasca settlements include Los Molinos, Llipata, Cordero Alto, and Tambo Viejo, and later local centers like La Muña, Parasmarca, Cerro Soldado and Tinguiña. Nasca populations declined around 300 CE as these local centers gained prominence, populations aggregated in other larger South Coast settlements, and Cahuachi was abandoned. While Paracas pottery was painted post-firing, Nasca ceramics were the first on the South Coast to be polychrome painted prior to firing. Nasca was also known for creating extensive geoglyphs in the shape of anthropomorphic and zoomorphic figures, lines, and geometric shapes across the desert, which might have been linked to water and astronomical alignments and used in ritual.

The terminal Nasca phases either coincide with, or were directly followed by, Wari occupations throughout the South Coast region, as indicated by Wari ceramic artifacts showing influence from the Central Highlands during the Middle Horizon (650-

1000 CE). Minimal excavations have been carried out in the South Coast Region for sites dating to this transition. In the Río Grande drainage, relevant investigated and known Late Nasca sites include La Tiza, Huaca del Loro, Tres Palos. Middle Horizon Wari sites include Pacheco, Pataraya, Lamrasniyoc and Chilcapuquio, and possibly a complex in the Ingenio Valley (Soßna, 2015:70). Overall, evidence indicates a gradual transition from the Early Intermediate Period into the Middle Horizon, and peaceful interactions with highlanders arriving in the area and merging with the Nasca culture while rule by local Wari government (70). The highland Tiwanaku culture also extended into some of the South Coast Valleys during this time, particularly in Moquegua. In the mid-valley, Magilligan and Goldstein (2001) suggest that expanded Tiwanaku settlement into the mid valley, concurrent with cultivation of agriculturally marginal lands, might have been the result of ENSO activity. ENSO might have induced highland droughts, or increased valley moisture to incentivize colonization (434).

The Late Intermediate Period (1000-1470 CE) on the South Coast saw the decline of Wari and the rise of the independent dominant coastal Chincha kingdom, or *señorio*. The entire Wari decline between 800-1000 CE is poorly understood, but might be due to multiple factors ranging from political instability to disease and invasion within the Wari heartland of Ayacucho. In the Nasca area, Wari centers were abandoned and population dramatically declined from 800-900 CE (Soßna, 2015:71). The Late Intermediate Period is largely characterized as a period of instability and conflict throughout the Central Andes. Major South Coast sites and settlements from this period were La Centinela (the Chincha administrative capital), Tambo Colorado in Pisco, and Ica La Vieja, which may have been the capital of a smaller kingdom in the Ica Valley (72). The Nanasca culture occupied the Río Grande drainage during this period, and sites include: Huayuri, Pinchango Alto, and Pajonal Alto. The Rucanas culture occupied the headlands of the drainage and the highlands. The Acarí and Yauca valleys seem to have had large village sites, like Sahuacari and Otaparo, but no monumental architecture.

The Chincha polity supposedly dominated a tightly organized maritime economic network extending north to Ecuador, although it is unclear whether this was achieved prior to incorporation into the Inca empire. Regardless, the kingdom seems to have been highly centralized with an estimated population of up to 30,000 people, organized into economic units of farmers, fisherman, and merchants (Rostworowski, 1970:137). The Inca Empire conquered Chincha during the Late Horizon (1400's -1532 CE) as part of a military effort against the neighboring Sora and Rucanas highlanders (Soßna, 2015:74). Accounts vary on the degrees of military involvement required to incorporate Chincha and the surrounding valleys, but the process is presumed to have been relatively peaceful in Chincha due to the Lord of Chincha's high status under the Inca.

In Chincha and Ica, the Inca seemed to have ruled through a state representative by constructing an administrative compound at La Centinela, the Chincha capital, and at Tacaraca in Ica. They constructed a similar sized administrative center called Tambo Viejo in Acarí. The Inca also built infrastructure in Pisco to secure this coastal-highland access route. Here the Inca built the foothill sites of Tambo Colorado (an administrative and storage site), Lima La Vieja, Huaytará, and Incahuasi (a royal spa), and constructed a major valley road (Soßna, 2015:74). The Inca ruled the Nasca drainage by constructing small administrative sites, including Tambo de Huayurí, Pueblo Nuevo, Tambo de Collao, Paredones, and Poromoa. in the foothills of each major drainage (75). Overall, during the Inca period the South Coast continued many of its administrative policies, with relatively less direct Inca influence than in other regions of the empire.

Subsistence and Agriculture

Subsistence is one of the primary reasons that humans interact with their environment, whether by accessing natural resources or modifying the landscape for agriculture. Climatic factors like precipitation and temperature are key for cultivating plants, and directly connect to water availability, which informs settlement decisions and agricultural technologies. On the South Coast, the excellent preservation conditions are conducive to diet reconstruction from archaeological data. Macrobotanical remains are commonly identified in excavations and on the surface of disturbed coastal sites, and together with some use of microbotanical methods, indicate a consistent group of cultigens that were increasingly utilized beginning in the Middle Holocene.

A major distinction and point of contention in coastal diet reconstruction has been the degree to which residents depended on cultivated plants and agriculture versus marine resources like fish and mollusks. This difference in the material cultural is important from a sociopolitical perspective because of longstanding debates on the subsistence base of the first coastal states. Michael Moseley's Maritime Hypothesis of the 1970's argued that the first coastal complex societies in the Andes were supported by marine rather than terrestrial resources, counter to traditional ideas of the role of agriculture in supporting population sizes and increasing sociopolitical complexity.

Data from some South Coast preceramic sites shows little evidence of terrestrial plant reliance. For example, the abundance and content of faunal remains at Jaguay and the Ring Site suggest heavy dependence on marine resources through the Pleistocene-Holocene transition, rather than a shift from terrestrial to marine strategies, although the Ring Site data shows greater marine species diversity (Reitz et al., 2016). Sandweiss et al. (2003) suggest a latitudinal gradient of climate correlates with subsistence for the Late Pleistocene/Early Holocene period because climate affected vegetation and the extent of the coastal plain (30). Although there are a limited number of coastal sites from this period, northern Peru sites appeared to have mixed hunting-fishing-gathering strategies while southern sites relied primarily on fishing (30). At Early Holocene sites Jaguay, the Ring Site, and Quebrada Tacahuay, occupants overwhelmingly relied on cool-water marine resources, including mollusks, echinoderms, sea mammals, crustaceans and seabirds (Sandweiss et al., 2003). For the Late Pleistocene through the Early Holocene, there was some reliance on terrestrial species at some locations. At Amotape in northern Peru, residents consumed mangrove mollusks (*Anadara tuberculosa*) and hunted mastodons, mammals, and birds inhabiting the adjacent Talara Tar Seeps. The species' distributions suggest greater seasonal precipitation in the area during this time period (Sandweiss et al., 2003:26-7), as at the Paijan sites, which probably improved these resource areas. Here, residents utilized tropical fish species, rodents, lizards, snakes, and birds, and analyzed dates from mastodon remains suggest the possible regional presence of megafauna during the Terminal Pleistocene.

Despite the predominant reliance on hunting and fishing for sites immediately on the coast, cultigens were already in use during the Late Pleistocene/Early Holocene transition. Some early evidence of cultigens on the South Coast is gourd excavated at Quebrada Jaguay, along with prickly pear cactus seeds (*Opuntia* cf. *ficus-indica*) (Sandweiss et al. 2003, 28). Maize has also received abundant attention in terms of its presence and abundance as part of Andean subsistence. The oldest maize remains for the Peruvian coastal region date to approximately 4750 BCE (6700 cal BP) at Huaca Prieta and Paredones on the North Coast (Grobman et al., 2012). On the North Central coast, maize was a primary utilized crop in the Late Archaic Period between 3000 and 1800 BC (Haas et al., 2013). Maize has also been documented at Initial Period (1850-450 BCE) sites on the South Coast, including Mastodonte (3745 BP +- 165 years), Hacha (3000-2700 BP), and Pernil Alto. However, maize was not found at Erizo (3890 BP +- 90 years and 3820 +- 85 years), a site roughly contemporary with Mastodonte (Silverman, 1996). Mastodonte's location along a now dry desert plain suggests this area must have been a better environment in the past, with waters from the Rio Seco. While this may be due to preservation and limited excavation, it could also suggest that maize was not a ubiquitous Initial Period crop in the South Coast region.

A number of Initial Period sites from the South Coast indicate that extensive agricultural crops were in use during by the middle of the last millennium BCE, particularly at inland occupations. Macroremains from Erizo in the lower Ica Valley indicate *Canavalia* sp., *Arachis hypogaea*, *Capsicum* sp., guayaba (*Psidium guajava*), pacay (*Inga* sp.) and cotton (*Gossypium barbadense*) (Silverman, 1996). Hacha, 23 km from the Pacific, above the Acarí River had remains of cotton, gourd (*Lagenaria sicaria*), lima beans (*Phaseolus lunatus*), *Cucurbita* sp., guayaba, peanut, aji, achira (*Canna edulis*), *Ipomoea batatas*, and maize. Animals like guinea pigs, camelids, and possibly deer were consumed at Hacha (Silverman, 1996). In the Nasca area at Pernil Alto, residents grew extensive crops including maize, lima beans, Common bean (*Phaseolus vulgaris*), giant bean (*Canavalia plagiosperma*), sweet potato, yucca, squash (*Cucurbita maxima*), calabaza (*Cucurbita moschata*), spaghetti squash (*Cucurbita pepo*), yam (*Pachyrhizus tuberosus*), bottle gourd, peanut, achira, and aji chili pepper (Soßna, 2015:144).

Besides agricultural products, Initial Period populations gathered wild resources such as pacay (*Inga feuillei*), guava, and edible portions of the *huarango* tree (*Acacia macracantha*) at Pernil Alto (144). Soßna (2015) argues that although Pernil Alto was located 15 hours walking from the Pacific coast, residents could also reach the upland headwaters above 2000 meters above sea level, and access surrounding forested floodplain for a diverse, complementary subsistence base (144). In the Nasca area, settlements were located inland during the Paracas period as well, so agricultural crops, rather than maritime resources, were the subsistence base and agricultural systems like large scale terracing were constructed as populations grew (153). Particularly during the Middle Paracas Phase (500-380 BCE), settlements expanded in the Nasca region across the headwater lands above 2000 meters above sea level, where they took advantage of rich farming lands (159). However, despite the distance to the coastline, floodplain seashells at Jauranga in show that occupants directly gathered marine resources from the coast, or procured them through trade (159).

On the coast, elite Paracas populations relied heavily on a diverse marine diet, while increasing agricultural intensification during the Paracas Period (Knudsen et al., 2015; Pezo-Lanfranco et al., 2015). On the Paracas Peninsula, Paracas Cavernas and Paracas Necrópolis elites used cultigens like gourds, yucca, pallares, jiquima, camote, peanut, lucuma, guayaba and increasingly, maize (Pezo-Lanfranco et al., 2015). These plants might have been procured locally, or obtained from either inland valleys (Engel, 1966), or through regional subsistence exchange networks (Paul, 1991). Non-elite coastal sites farther from the Paracas Peninsula (e.g. the fishing village Karwas) also utilized substantial amounts of plant foods and support evidence for increasing reliance on maize since at least the Paracas Period (Cadwallader, 2013). At inland mid-valley sites like Cerrillos, occupants also utilized both wild and domesticated plants, including maize, beans, yucca, achira, pacay, guayaba, avocado, lúcuma, cotton, and gourds (Wallace, 1962). Since at least the Late Paracas period in the lower Ica Valley, terrestrial resources became increasingly important.

By the Late Intermediate Period and the Late Horizon, a wide variety of agricultural crops were utilized at coastal sites, as evidenced by comprehensive microbotanical remains from Cerro Azul at the mouth of the Cañete Valley (Marcus, 2016). The plants include those documented for earlier periods, and the Spaniards introduced barley, vetch, rue, basil, and habanero peppers in the sixteenth century

(Marcus, 2016:231). During the Late Intermediate Period, populations at the site received agricultural products from inland sites, while Cerro Azul served as a fish processing center to move marine resources inland. However, populations also ate guanay cormorants and sea lions.

While most sites contained macro and microbotanical remains, the majority of studies over the past century have minimally employed microbotanical techniques that will help to mitigate different taphonomic responses and preservation. Recently, specific isotope studies (Knudsen et al., 2015; Pezo-Lanfranco et al., 2015; Cadwallader, 2013) have incorporated geochemical techniques that can generally distinguish between reliance on one or the other. Stone tools for cultivation, like hacha axes, are another indicator of agricultural activity and the importance of plants. For example, at the site Hacha, residents used stone hoes to cultivate plants within the seasonal Acarí River floodplain alongside the site (Silverman, 1996:116). Off-site archaeological investigations, for example Beresford-Jones, Lewis, and Boreham. (2009), can also further investigate associated remnants of agricultural fields and irrigation features that indicate the increasing commitments to agriculture.

Overall, coastal populations seemed to continuously rely on access to both marine and terrestrial resources as agriculture became the dominant means of subsistence during the Paracas Period. Marine resource dependence was determined in part by proximity to the coast, but marine resources were particularly important for smaller settlements through the late Holocene. They remained important through in this region throughout the prehistoric period due to regional exchange networks, even as sites became specialized.

Conclusion

The relevant climate data for the South Coast of Peru comes from a variety of proxy sources and records, and primarily addresses 1) global atmospheric-oceanic climate process, and specifically El Niño as a major climate driver for the Pacific Basin, 2) local scale evidence of specific ENSO-related flood events, and 3) local microenvironments and landscape modification within the desert. The most pronounced shifts in ENSO frequency and strength occurred on the order of millennia during the Terminal Pleistocene through the Early Holocene as modern ENSO and corresponding oceanic conditions were attained and sea level stabilized. Since then, the proxy data records flood events occurring decades or centuries apart that impacted the coastline to varying degrees. As discussed here, archaeological mollusks recovered from coastal sites provide long-term evidence of offshore oceanic conditions. Sediment cores supplement this ENSO record by linking terrestrial and oceanic evidence within the same record to reconstruct ENSO frequency shifts for the entire Andean coastline since the Late Pleistocene and localized flood events. Continental geomorphological evidence also records local scale ENSO-related floods that can corroborate patterns suggested by the broader scale data. Archaeological settlement patterns, terrestrial fauna, suggest arable locations like lomas, wetlands, and woodlands, as well as periods of more moist conditions, like winter fog, within the desert region.

Together, these proxies indicate microecosystems within the desert, that importantly, were regulated by local physical conditions like temperature and precipitation controlled by atmospheric scale ENSO processes. For example, Machtle and Eitel (2013) make a direct case for the deterministic nature of climate in the Nasca Region with reconstructed vegetation changes from the Late Pleistocene through the Holocene. Their loess-paleosoil analysis indicated that moist conditions peaked during the Middle Holocene when the region became a stable grassland along the western slope of the Andes from 2200-300 meters above sea level between 9500 and 2150 BCE (11,500- 4100 cal BP). Prior to this during the Late Pleistocene, the Palpa area was a semi-desert due to moisture moving across the Andes and increasing river flows around 11,550 BCE (13500 cal years BP). Aridity increased with the onset of modern ENSO conditions by approximately 2250 BCE (4200 years cal BP), returning this zone to hyperarid desert, as it is today. Since water constrains settlement and especially agriculture, this evidence links local Holocene human occupation history with global climate, especially in terms of daily subsistence and resources access.

Soßna's (2015) comparison of archaeological settlement data with existing geomorphological and sediment data for the Nasca Region relies on these associations between subsistence and arable zones within the coastal desert environment. His data provides one of the most long-term, comprehensive localized analyses of correlations between climate and culture within the South Coast Region. Soßna frames human-environment relationships in terms of settlements and subsistence bases by describing the agriculture and resource potential of specific settled altitudinal zones of the Nasca-Palpa region. Cultural and sociopolitical factors also influence settlement patterns, and settlement data can have inconsistent and coarse temporal resolution without accompanying excavations. Overall, however, correlations between settlement and paleoenvironmental data do suggest testable hypotheses for additional investigations.

Soßna's results are for the Nasca-Palpa region, so a critical question is the extent to which observed climate impacts can apply to the broader South Coast region. The Río Grande de Nasca drainage differs geomorphologically and hydrologically from other valleys on the South Coast in size and proximity to the coast. Soßna's study region was from 300 to over 4000 meters above sea level, and as a result, many of the observed settlements are situated in higher altitudes and ecozones than, for example, many of the Paracas period sites in the floodplains of Chincha and Pisco, or sea-level beachside settlements at other valley mouths. As precipitation and temperature correlate highly with the Andes altitudinal gradient, the climatic data utilized in this study applies best to the inland foothills. However, the cultural history of the South Coast demonstrates that this watershed was not culturally isolated, and some of the specific human responses to climate changes suggested by this study for this area might have traceable archaeological correlations in other valleys of the region.

Increasingly, available proxies and paleoenvironmental records have motivated more researchers to investigate causal links and temporal correlations between dramatic climate changes and rapid social change (Van Buren, 2001:141). Due to ENSO's sometimes severe effects, ENSO history has been implicated in archaeological research for decades throughout the region, with what Contreras (2010) describes as "varying degrees of subtlety" (259) at both broad and local scales. As mentioned in this report, examples of cultural transitions include the rise and fall of Tiwanaku, and the decline of monumental coastal centers. In some cases, archaeological data provides direct chronological evidence of human responses to climate events. The clearest direct evidence of responses to major ENSO floods was dam enlargement around 3339-3907 years ago at the site of Manchay Bajo to protect the temple from mudslides from the nearby ravines. Of the major centers in the region that existed between around 3800-800 BCE (5800-2800 cal BP), Manchay Bajo existed the longest, suggesting that leaders buffered against more frequent ENSO flood risks during the shift in ENSO frequency at approximately 1000 BCE (Sandweiss et al., 2001:605). This shift suggests that coastal residents could have experienced floods on the order of several times a decade, as with modern conditions, rather than once a generation (605). The authors state the general need for more data to test these relationships of correlated climatic and sociopolitical changes, but suggest this example shows how climate and culture are connected "in a complex causal network" (605).

Contreras (2010) points to additional, specific correlated responses, and for the South Coast, geomorphological evidence of flood deposits associated with archaeological sites offers the strongest direct correlation between flood events, or landscape modification, and cultural or settlement changes. However, these are particular, local-scale associations, rather than broad scenarios to describe entire cultures, and major collapses and declines, beyond a single site, generally result from complex interacting factors. For example, Van Buren's (2001) critical analysis of archaeological research focused on the “disastrous” results of the Miraflores ENSO flood event around 1350 CE, and she emphasizes that the variability of human response and social vulnerability are crucial themes to understand the interplay between ENSO and prehistoric populations (139-40). Although many studies have posited “disaster” correlations that are supported by variable amounts of evidence, Van Buren argues for greater attention to social factors, by incorporating modern hazard research and theories from political ecology (142).

Soßna’s (2015) settlement pattern work also highlights that climate-culture correlations do not necessarily exist, even in landscapes where dynamic environmental factors are at play. He concludes that despite a series of major settlement shifts and cultural declines for the period from 1500 BCE-1532 CE, “temporal correlations between significant changes in climate and major cultural developments are rare” (269) for the Río Grande de Nasca area. In his study, the earliest major settlement change is the highland population increase during the Middle Paracas phase, and subsequent decline of these sites in the Late Paracas phase as the Topará and Nasca cultural traditions emerged across the South Coast. Soßna attributes the first shift to the arrival of highlanders, and the second relocation to the arrival of Ica Valley people in the Palpa region (265). The arid but stable climate from 400-200 BCE may have facilitated highland settlement, but would not have caused the decline that followed (267).

Another population shift occurred with a sudden Nasca collapse of populations concentrated in the foothills around 300 CE, but this too was probably due to sociopolitical factors rather than any change in what appear to have been stable precipitation patterns (267). This was followed by population recovery, and a restructuring as the headlands were possibly reoccupied by highland immigrants. Over the course of Wari control of the region, and specifically the headlands, throughout the Middle Horizon, the foothills and headlands were abandoned (266). Soßna suggests that low precipitation in the 700's CE might have contributed to abandonment, but also that the area was not resettled when precipitation levels increased from 900-1050 CE (269). Until the Inca Period, interethnic violence increased with population as immigrant groups settled the study region. However, local practices appear unchanged despite hyper-arid intervals from 1050-1250 CE and since 1440 CE that theoretically should have hindered agricultural production (269). Population, and agricultural extent, reached its height in the 1400's CE, and declined following Spanish conquest of the Inca Empire. While there is no evidence that climate, in terms of precipitation, aridity, and stability, was causal in any of these events, it may of course have been a contributing factor. This work also demonstrates that increased rainfall and ameliorated environmental conditions do not necessarily directly correlate with expanded human occupations. Conversely, hyperarid periods do not always disrupt local lifeways, and environmental archaeology research needs to consider the complexities of human responses.

Human impacts also need to be considered as significant forces affecting landscape change on the South Coast, on a different time scale from climatic perturbations like severe, periodic ENSO floods that impacted these valleys. Evidence from the Samaca Basin suggests dense forests in the South Coast valleys mitigated erosion during ENSO floods and also enhanced soils as agriculture expanded regionally during the Early Intermediate Period (Beresford-Jones et al., 2009; Beresford-Jones, Lewis, and Boreham, 2009). Gradual human deforestation in the basin undermined the landscape's resilience, resulting in rapid desertification and abandoned settlements following a major ENSO flood event. Sediment records are particularly valuable for showing both natural and human events and impacts to comprise a history of human-environment interaction.

Overall, correlating climatic data with archaeological history is limited by data resolution, as processes and events are recorded on different scales. Multiple factors, including the error ranges of paleoclimatic data, the existence of comprehensive records, and the availability of radiocarbon dates, complicate composite chronologies, and it is challenging to disentangle and isolate environmental influences from within the archaeological record. In many cases, data resolution is simply not high enough to discern specific culture-climate interactions or determine dramatic cultural changes with any certainty. For example, Soßna (2015) reasons that hyperarid periods would have theoretically had the greatest influence on culture history in the Río Grande de Nasca drainage. However, his settlement data showed that populations were already low during the 11th and early 9th century BCE and 8th century CE (269), so while climate undoubtedly had an impact (269), it was not observable at the scale of subsistence and settlement patterns because agricultural production was probably still sufficient to support these population levels during this time period. In another example, Zaro et al. (2013) concluded that chronological resolution was too poor to discern direct relationships between environmental perturbations and human events, despite the occurrence of severe El Niño floods during the time of occupation at the site of Cola de

Zorro. Flood-related sediment deposits identified within the adjacent river drainage were not found at Cola de Zorro, so there was no evidence that ENSO flooding directly impacted the site or the population in a catastrophic way. More dated samples, refined dating techniques, and attention to error ranges within archaeological research will help align archaeological data, which has been based fundamentally in stylistic chronologies, with climatic data, which relies on chemical dating techniques. Understandably, the severe events occurring within the Andean environment have been a central focus of many archaeological studies in the central Andes (Contreras, 2010). While dramatic declines would be theoretically most visible within these data sets due to scale, higher resolution data, such as archaeological excavations and associated radiocarbon dates from sites occupied during the periods highlighted by the most extreme climate shifts would probably reveal additional subtle human responses to these climate changes, such as adaptive changes and resilience. For example, while neither the Chuza (around 1600 CE) nor Miraflores (1300's CE) ENSO flood were found to have directly caused site abandonment at Cola de Zorro in Ilo, the Chuza events may have impacted subsequent land use, seen by the increase in herding practices after 1600 CE (Zaro et al. 247-78).

Although it is challenging to infer the direct causal effects of climate on major cultural transitions for the South Coast, climate processes would have been inextricably tied to resources and subsistence since the beginning of human occupation. For a region so heavily associated with the Pacific Ocean and marine species, the dynamic nature of the ocean not only had implications in terms of natural hazards like tsunamis and storm surges but also in terms of subsistence on short-term time scales. Marcus (2016) makes the important point that “the sea cannot be treated as a mature ecosystem with predictable resources” (19) because the anchovy, sardine, and mollusk populations and ranges fluctuated according to global scale ENSO frequency shifts. Similarly, ENSO flooding would have directly impacted water availability in the coastal valleys, where people gradually committed to agriculture over a long trajectory that originated in reliance on moist wetland and lomas zones. These processes show that oceanic- atmospheric climatic processes, and specifically ENSO, had direct impacts on daily human adaptations and lifeways on the South Coast. Multi-proxy data and approaches, with archaeological evidence, will continue to resolve ancient climate across the Andes to advance our understanding of human-environment interactions beyond simple correlation and on finer time scales.

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