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EL NIÑO IN PERU: ARCHAEOLOGICAL PERSPECTIVES

EL NIÑO EN PERÚ: PERSPECTIVAS ARQUEOLÓGICAS

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Abstract

El Niño is a global climatic phenomenon that can affect human life. Consequences for the coast of Peru are particularly strong. Here, we discuss the most important varieties of El Niño, outline costs and benefits of each, and offer a summary of the role that El Niño has played in Peruvian archaeology based principally on our own research over four and a half decades. There are two research trends in the archaeology of El Niño in Peru: using archaeological remains to identify past events and frequencies of canonical El Niño events and trying to understand how humans have interacted with El Niño over the millennia of human presence on the Peruvian coast. Peruvian archaeological data were among the first indicators of variation in El Niño frequency over time and continue to shed light on El Niño behavior. Over the last half century of archaeological El Niño studies, archaeologists' perspectives have shifted from seeing the phenomenon as a disaster to recognizing human agency – the ability

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of past Peruvians to show resilience in the face of El Niño stressors. We conclude with some suggestions for future research on the archaeology of El Niño in Peru.

Keywords: El Niño Southern Oscillation, Andean archaeology, paleoclimate, history of El Niño, climate change.

Resumen

El Niño es un fenómeno climático global que puede afectar la vida humana. Las consecuencias para la costa del Perú son particularmente fuertes. Aquí, describimos las variedades más importantes de El Niño, listamos los costos y beneficios de cada variedad, y ofrecemos un resumen del papel que El Niño ha jugado en la arqueología peruana basado principalmente en nuestra propia investigación durante 45 años. Hay dos tendencias de investigación en la arqueología de El Niño en Perú: utilizar los restos arqueológicos para identificar eventos y frecuencias de eventos canónicos de El Niño en el pasado y tratar de comprender cómo los humanos han interactuado con El Niño a lo largo de los milenios de presencia humana en la costa peruana. Los datos arqueológicos peruanos estuvieron entre los primeros indicadores de la variación en la frecuencia de El Niño a través de los milenios y continúan arrojando luz sobre el comportamiento de El Niño. Durante medio siglo de estudios arqueológicos sobre El Niño, las perspectivas de los arqueólogos han pasado de ver el fenómeno como un desastre a reconocer la acción humana: la capacidad de los peruanos del pasado para mostrar resiliencia frente a los factores estresantes de El Niño. Concluimos con algunas sugerencias para futuras investigaciones sobre la arqueología de El Niño en Perú.

Palabras clave: ENSO, arqueología andina, paleoclimatología, historia del fenómeno de El Niño, cambio climático.

The 1982-82 El Niño event called widespread attention to this climatic phenomenon. It became a household word throughout the world during the 1997-98 event, due to both the strength of the event and the growing availability of internet-driven social media. Inspired by this notoriety, one North American musician even wrote and recorded the song "Blame it on El Niño" (Shropshire 2000) and it has become a part of pop culture (search on "El Niño" and jokes or memes). Scientists have been aware of El Niño since the end of the 19th century. Beginning in the second half of the 20th century, it has been the focus of an increasing number of studies (76 in the 10 days between October 24 and Nov 3, 2024, according to Google Scholar). By the 1960s, scholars of ocean-atmosphere interaction had recognized that El Niño is just part of a larger, Pacific Basin-wide system called El Niño/Southern Oscillation (ENSO), with teleconnections to many other parts of the globe. Stevenson and Wicks (1975) listed almost 600 articles in their "Bibliography of El Niño and Associated Publications", and that was before the huge increase in research spurred by the 1982-83 and 1997-98 events.

Archaeologists first began taking El Niño into consideration in the late 1960s and among us, too, it has been the focus of increasing interest. Of course, those who live on the coast of Peru have always been aware of the phenomenon—and have dealt with both the catastrophes and opportunities presented by El Niño's arrival. This includes indigenous people who have inhabited the Peruvian coast for over 13,000 years and who have much to teach us.

We have constructed this paper to offer a brief summary of El Niño as it applies to studies of prehispanic Peru. We begin by defining what El Niño is and the flavors or varieties of El Niño that are important for life on the Peruvian coast and sometimes elsewhere in the region (Sandweiss et al. 2020). In this discussion, we also look at both positive and negative aspects of events and frequency trends. Although we refer to El Niño throughout the paper, it is important to recognize that El Niño is always a part of ENSO. Following the section on El Niño flavors, benefits, and costs, we summarize techniques for recognizing El Niño in association with archaeological sites. Next, we offer a summary of El Niño in archaeological studies of this region. There are two trends in this research techniques for recognizing El Niño in association with archaeological sites:

1) Using archaeological remains to improve understanding of when and how often El Niño occurred. The Peruvian coast has almost no natural, medium to high resolution natural climate archives (e.g., lake cores, ice cores, ocean cores, corals) that cover the entire period of human coastal occupation and/or directly reflect coastal climate. Archaeological studies of El Niño in Peru thus contribute to global studies of paleo-ENSO (see Sandweiss et al. 2020).

2) Studying El Niño's human impacts. When archaeologists first began to consider the role of El Niño in cultural development on the prehispanic Peruvian coast, they (and that includes us) generally thought of El Niño as a disaster. As Cecilia Mauricio (personal communication, 2024) has pointed out, that perspective probably arose in part because El Niño in the 20th century often was an unmitigated disaster. Spurred in part by Van Buren's seminal paper (Van Buren 2001), there has been a growing recognition that prehispanic people on the Peruvian coast found ways to mitigate and perhaps even use the various El Niño impacts to their benefit.

These two lines of research overlap, as will become clear in the following pages. We recognize that we rely heavily on our own research, which began in 1980 with Sandweiss's visit to the Ostra paleobeach and Ostra sites north of the Santa River on the coast of Peru (Rollins et al. 1986a; Sandweiss et al. 2007; inter alia). There are hundreds of papers on El Niño and Peruvian archaeology. We cannot mention or do justice to all of them, and whatever we have omitted is not a reflection on the value of that work. We apologize in advance to those who are not cited.

We conclude this paper by considering some of the things that need to be done to keep advancing our understanding of El Niño in prehispanic Peru.

El Niño on the Peruvian Coast: Flavors, Benefits, and Costs

El Niño/Southern Oscillation (ENSO) dominates present-day climatic variability on interannual timescales in the tropics and involves both the atmosphere and the ocean in the tropical Pacific. Warmer than normal central Pacific Ocean Sea surface temperatures (SST) occurring about every 2-7 years define El Niño. Cooler than normal SSTs in this region are called La Niña. This interannual variability of SST is coincident with a modulation of the sea level pressure gradient across the tropical Pacific that gives rise to a weakening and strengthening of the trade winds called the Southern Oscillation. Although EI Niño is a Pacific basin phenomenon, its influence extends north and east throughout the Americas, west to India and Africa, and elsewhere (see Maasch 2008 for a summary of EI Niño teleconnections across the Americas). As part of ENSO, El Niño has many different varieties or flavors (Capotondi et al. 2015, Timmermann et al. 2018). Four are particularly important for Peru: Eastern Pacific El Niño (EP-EN); Coastal El Niño (COA); Central Pacific El Niño (CP-EN), also known as El Niño-Modoki; and La Niña (LN). The following sections are drawn mainly from Sandweiss et al. (2020) and Sandweiss and Maasch (2020).

Eastern Pacific El Niño (EP-EN)

EP-EN events are the canonical El Niño and were the first flavor that was widely recognized. When studies through the 1990s referred to “El Niño”, they meant EP-EN events. During EP-EN, trade winds weaken, anomalous warming in the central Pacific propagates eastward to the Americas, the thermocline in the Eastern Pacific deepens, a warm-water pulse reaches the Peruvian coastal zone, and coastal upwelling weakens. This causes sea surface temperature (SST) in the region to warm, nutrients to diminish, and marine biomass to decrease (e.g., Arntz et al. 1985; UCAR/NOAA 1994). Increases in SST during EP-EN are generally strongest to the north and weaker to the south. Although there is some replacement of warm-adapted species, available marine resources are reduced and can cause food stress for humans and other organisms who rely on these resources, particularly from Lima at 12˚ S and to the north. South of 12°S artisanal fishers may sustain their fishery with replacement species, as they did at Cerro Azul during and after the EP-EN in 1982-83 (Marcus et al. 2020; see also Arntz et al. 1985).

Around the Pacific basin, the precipitation patterns that dominate non-El Niño years tend to reverse in an EP-EN event: The western Pacific becomes drier, while the eastern Pacific, including the desert coast of Peru, becomes wetter. Warmer coastal waters support convective storms onshore leading to destructive flooding across the normally arid landscape, with consequent damage to coastal infrastructure such as irrigation, field systems, and transportation networks, particularly north of 12°S. Locally, rains can cause debris flows that can be harmful to modern and ancient habitation and ceremonial sites, as we have observed at the Salinas de Chao site (Kelley et al. 2022). Floods transport large quantities of sediment to the coast. The amount of sediment available for this transport into the coastal zone is enhanced by earthquakes; seismic activity produces loose rubble and destabilizes drainage patterns, with the result being extensive erosion during torrential El Niño rainfall (Sandweiss 1986). Some of this alluvial silt is deposited across field systems by overbank flooding, providing fertile soils for subsequent agriculture, as in the Nile system but occurring at less frequent intervals. El Niño rains cause the desert to bloom with plants, some of which are useful to people. The rains also provide opportunities for rainfall farming. On the other hand, pooled water creates ideal conditions for insect populations to explode. Many of these insects are vectors for diseases such as malaria, zika, chikungunya, and dengue (e.g., Gagnon et al 2002).

Along river margins, sedimentary floodplain deposits can eventually raise the land surface above most floods and create safe zones for site construction. The Moche seem to have recognized this. At both San José de Moro in Jequetepeque (under excavation by Luis Jaime Castillo since 1990, e.g., Castillo Butters 2011) and Huaca de la Luna in Moche (excavated by Santiago Uceda, e.g. Uceda 2010), construction took place on land surfaces created by flooding and eventually elevated above the level of frequent high flow events; these surfaces were not subsequently damaged by flooding of the adjacent rivers (Sandweiss and Maasch 2020: 967-970; Pluta 2015).

Much of the sediment load eroded by El Niño rainfall is carried to the sea, where it forms temporary deltas at river mouths. Some delta sediments are subsequently carried north by wind and currents to form beach ridges parallel to the shore (e.g., Shafer Rogers et al. 2004). Sandweiss et al. (2009) showed that sand blown inland from the coastal ridge in the Supe Valley reached Late Preceramic sites as far inland as Caral and may have damaged agricultural productivity enough to account for abandonment of most monumental sites in the region at the end of this period. Wells used archaeological settlement patterns to demonstrate how flooding of the Santa River created new land at the river's delta, which people subsequently settled (Wells 1992). A similar process occurred on the Chira Beach ridge plain (Richardson 1983; Belknap and Sandweiss 2014). Standing water from torrential rainfall and flooding in these environments has its own hazards, destroying crops and promoting insect-borne diseases (Gagnon et al. 2002; Kovats et al. 2003).

Coastal El Niño (COA)

In February and March of 2017, what at first seemed to be a large-magnitude EP-EN event devastated the north coast of Peru. Climatologically, it was quite different from EP-EN and is identified as a COA. During this occurrence, SSTs along the coast from Ecuador to Lima were abnormally high and led to torrential rainfall. However, unlike an EP-EN event, Central Pacific SST remained normal. Reanalysis of records from 1979 to 2017 revealed 7 COAs, some of which followed large-magnitude EP events and prolonged the negative consequences for coast dwellers (Hu et al. 2019). The large-magnitude 1925 El Niño was also a COA (Takahashi and Martínez 2019). At the end of the 2017 COA event, the Peruvian government reported 101 flood-related deaths, 939,713 people displaced, 353 wounded and 19 missing persons (RPP 2017). A year later, Caramanica (2018) provided updated, worse numbers: "158 flood-related deaths, 1,372,260 people displaced, and 3.124 billion dollars in damage"—over 1% of Peru's gross domestic product. For people living on the Peruvian coast, especially north of 12°S, COA and EP events have similar consequences: Fishing is diminished, coastal infrastructure is damaged or destroyed, insect-borne diseases are rampant, and sediment transport drives coastal progradation.

As we have been pointing out for almost 30 years, there is a major climate divide at 12˚ S (i.e., Lima). Soil development (Noller 1993), lomas plant communities (Rundel et al. 1991, 1998; Rundel and Dillon 1998), and records of marine productivity and SST in cores from the continental shelf (e.g., DeVries and Schrader 1981; Salvatteci et al. 2019; see Figure 2 in Sandweiss et al. 2020a) all differ north and south of 12°S. The fact that COA SST anomalies are confined largely to the coast north of 12°S supports the climate divide at that point. Archaeologically, it would be very difficult to distinguish evidence for a COA event or changes in COA frequencies from EP-EN events or frequencies. If much of what has been considered as EP-El Niño in northern Peru (at and north of 12˚ S) was actually COA, over the time since humans arrived in Peru, SST anomalies and associated coastal rainfall would have been even less to the south of that point than the latitudinal gradient of EP-EN would suggest. As we suggested recently (Sandweiss et al. 2020a), more frequent COA events in the past could explain the differences in our north-coast based reconstruction of paleo-El Niño history in northern Peru and Carré et al.'s (2014) reconstruction based on isotopic studies of *Mesodesma donacium* shells from sites south of 12˚ S.

Central Pacific El Niño (CP-EN)

In the early 2000s, Japanese scientists recognized another flavor of ENSO: CP-EN or Modoki-EN (Ashok et al. 2007; Wang and Wang 2013). During a CP-EN event, the central Pacific warms anomalously, but the warm water does not propagate to the Peruvian coast; rather than warming, Peru has slightly cooler SST anomalies during CP-EN. CP events do have atmospheric teleconnections around the Pacific Basin, generally changing the precipitation regime from wet to dry or dry to wet. In the Andean highlands, CP-EN is usually associated with drier conditions (e.g., Ashok et al. 2007; Wang and Wang 2013; Taschetto and England 2009; Weng et al. 2009; Zhang et al. 2014) with significant reductions in stream flow to the Peruvian coast (Rau et al. 2017; Sulca et al. 2018; Sandweiss 2019). Because CP events negatively affect irrigation-based agriculture on the north coast today, they likely would have done so if they occurred in the past. There are few records of CP-EN events before the instrumental record of the last century. Freund et al. (2019) used coral records to reconstruct the past four centuries of CP-EN events, while Liu et al (2017) used oxygen isotopic from tree cellulose in Taiwan to create an eight-century record of CP-EN. These studies rely on different proxies, and neither is directly relevant to coastal Peru.

La Niña (LN)

Rather than the anomalous heating and associated coastal rainfall of EP-EN and COA, La Niña is an exaggeration of normal (non-El Niño) conditions (Glantz 2002; McPhaden 2003). The Pacific Basin cools and the Eastern Pacific margin (including Peru) becomes drier (Cai et al. 2015). On the Peruvian coast, the human consequences of LN are much less severe than EP-EN. Malarial epidemics are not reported for LN (Gagnon et al. 2002), but health consequences on the north coast include respiratory problems (Ordinola 2002). Fisheries are enhanced by the intensified LN cooling, although agricultural outcomes are mixed (Ordinola 2002).

Table 1.
Direct positive and negative effects of ENSO on the Peruvian coast.

Effect	**Positive**	**Negative**
Some marine species replacement	√	
Desert bloom	√	
Rain for opportunistic agriculture	√	
Resilience farming	√	
Soil replenishment	√	
Algarrobo forest renovation	√	
Landscapes “safe” for construction	√	
Crisis management	√	
Marine biomass loss		√
Torrential rainfall leading to desert erosion and debris flows		√
Destruction of crops		√
Destruction of infrastructure		√
Coastal change		√
Insect plagues and disease epidemics		√
Population dislocation		√

Summary of Positive and Negative Effects of ENSO Events

Although most archaeologists originally considered El Niño to be an unmitigated disaster, we now recognize that ENSO on the Peruvian coast has both positive and negative effects for human inhabitants and that past human societies were able to mitigate some of the negative effects; this is a topic to which we return later in the paper. **Table 1** summarizes the direct impacts of El Niño mentioned above (see Sandweiss and Maasch 2020 for more details).

Identifying El Niño in Archaeological and Natural Records in or Associated with Archaeological Sites

Here and in the following section on El Niño in Peruvian archaeology, we use "El Niño" to refer to Eastern Pacific El Niño and Coastal El Niño, that is, the flavors of El Niño that cause SSTs to warm, the thermocline to drop, and torrential rainfall to occur along all or part of the Peruvian coast. This region is unusual in terms of the natural archives (proxy records) available for studying past climates–including El Niño. As we have pointed out for several decades (e.g., Sandweiss 2003; Sandweiss et al. 2007, 2020a; Sandweiss and Kelley 2012), the most frequently used high resolution records of past climate (ice cores, corals, lake sediments) respond in part to climatic influences from the Atlantic or are mostly absent from the study region. Consequently, for the last ~13,000 years, archaeological deposits are important sources of such information. We have divided sources of paleoclimatic data relevant to the past behavior of El Niño on the Peruvian coast into low, medium, and high-resolution records (Sandweiss et al. 2007; see also Sandweiss and Kelley 2012 and Sandweiss et al. 2020b: Table 1 for further information on natural and anthropogenic proxies for past climate).

Low resolution records of El Niño on the Peruvian coast are not anthropogenic but contribute to our understanding of El Niño frequency during the Holocene. These records include flood deposits, beach ridge morphology, lomas (xerophytic vegetation) distribution, and soil development. Flood deposits on the coast of Peru often result from El Niño-derived rains; dated flood deposits have a hiatus between about 8900 and 5700 cal BP (e.g., Fontugne et al. 1999; Keefer et al. 1998, 2003), which fits our hypothesis of a hiatus in El Niño activity at that time.

Beach ridges in northern Peru were built through a combination of seismic activity producing loose debris on the unvegetated slopes of coastal hills, El Niño rainfall washing the sediment into rivers and carrying it to the coast, and longshore processes distributing sediment northward as ridges (Sandweiss 1986; Shafer Rogers et al. 2004; Belknap and Sandweiss 2014). Dated ridge sequences, particularly the Chira ridges, show a change in size and style of ridge formation about 3000 cal BP, supporting our hypothesis that El Niño frequency increased at about that time (Shafer Rogers et al. 2004; Belknap and Sandweiss 2014).

Stands of lomas vegetation are basically one community from Lima (12˚S) to the north, while stands to the south of Lima have many endemic species (Rundel and Dillon 1998; Rundel et al., 1991). To the north of Lima, soil development has occurred outside the valley bottoms, while to the south of Lima it has not (Noller 1993). The lomas and soil distributions support the existence of a climatic divide at about 12˚S on the Peruvian coast, as does the extent of warming and torrential rainfall during Coastal El Niño (Sandweiss et al. 2020a).

Cores from lakes and from the continental shelf and terrestrial flood records have medium resolution (~centennial scale resolution). Other medium resolution records include isotopes from mollusks that have been used to create a medium resolution reconstruction of Holocene El Niño behavior in southern Peru, and biogeography of mollusks and fish that have been used for similar purposes on the north coast.

Lakes are largely absent from the Peruvian coast because it is a desert, outside of immediate well-watered river valleys. Working with paleolimnologist Curt Stager, we are developing a record from the ephemeral lake known as "La Niña" that forms in the Sechura Desert of northern Peru during El Niño and evaporates in subsequent years (Sandweiss and Maasch 2020:988). Rodbell et al. (1999) and Moy et al. (2002) analyzed sediments from Laguna Pallcacocha in Ecuador and recovered data that may reflect past ENSO frequencies. As we have noted (Sandweiss et al. 2020:8274), Schneider et al. (2018) have raised some concerns about the role of El Niño in creating the Pallcacocha record.

Marine cores from the shelf are more promising, although they often have an unconformity (missing sediment) in the crucial mid-Holocene. Some cores appear to be continuous and can offer some evidence of past El Niño activity. Sandweiss et al. (2020a) briefly review the core records and provide citations to relevant papers. Of particular interest here, Rein et al. (2004, 2005) published their analysis of Core 106 KL, on the continental shelf 80 km to the west of Lima. They used lithic concentrations as a proxy for El Niño intensity. Among their findings are what appears to be a period of low or absent El Niño from about 6000 to 8000 cal BP, the same period that we have identified as a hiatus in El Niño activity (Sandweiss et al. 1996, 2020a inter alia; see below). Rein et al. (2005) note that this is also the period of lowest resolution in their record, although that might be related to decreased sedimentation due to a lack of El Niño floods. Rein et al. (2004) also identified a decrease in El Niño activity during the Medieval Climate Anomaly, from about 800-1250 CE, following peak intensity at about 750 CE (see below and Sandweiss and Maasch 2022 for consideration of this record in light of Lambayeque Valley archaeology).

Flood deposits from archaeological sites can indicate the precise moment of El Niño presence at the site (see below). Compiling flood off-site records along the coast offers some insight into El Niño presence or absence. El Niño related flooding appears to be absent (or at least hasn't been dated) during our proposed hiatus from 9000/8000 to 5800 cal BP (see above and Sandweiss et al. 1997: 967; Sandweiss et al. 2007: 34; Fontugne et al. 1999; Wells 1987, 1990).

Carré et al (2014) analyzed stable isotopes from *Mesodesma donacium* clams (machas) along the coast of Peru from Lima to the south to create a record of Holocene El Niño frequencies. We discuss this record further below.

Through a series of publications, we have used the biogeography of mollusks and fish to establish and refine an El Niño chronology for the north coast of Peru. Based on mollusks from the Ostra sites on a paleobeach north of the Santa River and comparison to molluscan assemblages from nearby but later sites, we (Rollins et al. 1986) first proposed that the north coast was significantly warmer for part of Mid Holocene and El Niño could not have functioned as it does today. This was one of the first papers to suggest that El Niño frequency changed over time. In 1996, in response to critiques of our earlier work, we (Sandweiss et al. 1996) published a meta-analysis of fish and molluscan data from along the Peruvian coast and through time. This work supported our original hypothesis and defined the southern limit of warming as ~10˚S. Andrus et al. (2002) used stable isotopes in otoliths of sea catfish (*Galeichthys peruvianus*; bagres) from the Ostra Base Camp (north of the Santa River) and the Siches site (north of Talara) to show that SSTs in the Mid Holocene in these locations were about 3˚C warmer than today. At Ostra Base Camp, Andrus found that over the life of the catfish, summer SSTs reached El Niño levels, but winters were as cool as they are today. This finding explains why sedentary mollusk species at the site are all ones that live in or tolerate warm SSTs while the fish assemblage includes some cool water species (Reitz and Sandweiss 2001). Sandweiss et al. (2001) looked at the temporal and spatial distribution of two molluscan species (*Mesodesma donacium* and *Choromytilus chorus*) that become locally extinct when SSTs reach El Niño temperatures for weeks or months. Those data both supported our original hypothesis (a permanently warm north coast prior to about 5800 cal BP [5000 14C BP]) and indicated that between about 5800 to 3200/2800 cal BP, the north coast had cool SSTs and infrequent El Niño events. After 3200/2800 cal BP (now thought to be about 2900 cal BP), El Niño became much more frequent. Recently (Sandweiss et al. 2020a), we reviewed the data and interpretations of Holocene El Niño frequency on the Peruvian coast that we and others have generated since noted that when 1986 and suggested a way that Carré et al.'s (2014) reconstruction for the Peruvian coast south of Lima might work with our reconstruction for the coast to the north of Lima. This history of study is reviewed below in more historical detail.

There are two kinds of high-resolution El Niño proxies: those that can offer a continuous high-resolution record, such as ice cores and corals, and those that offer short term records for identifying El Niño at specific moments in the archaeological record. Corals are not found along the coast of Peru. There are many studies of El Niño in corals elsewhere in the Pacific with ENSO signals (e.g., Tudhope et al. 2001; see Lu et al. 2018 for a review of paleo-ENSO records with references to more recent coral records), but they do not relate directly to climatic events on the Peruvian coast. Lonnie Thompson and colleagues' (1984, 1985) work on cores from the 1500-year Quelccaya Ice Cap (updated to an 1800-year record by Thompson et al. in 2013) has been used frequently by archaeologists as a proxy for precipitation across the Central Andes (e.g., Shimada et al. 1991). Thompson et al. (1984) suggested that "[t]he Quelccaya ice cap…may provide a long and detailed record of the most extreme ENSO events". However, as Chepstow-Lusty et al. (2003: 500) noted and as we discussed more recently (Sandweiss et al. 2020: 1874), this correlation may not be fully valid.

Short term records that help archaeologists identify specific El Niño events in archaeological sites include the remains of mollusks, fish, and plants, as well as erosional and depositional features incorporated into archaeological sites. These indicators of El Niño have the advantage of being in direct association with moments in the archaeological past and can be dated directly or by stratigraphic association with other dated materials. A disadvantage is that records of events in a particular archaeological site may provide a sequence within that site, but cannot be exactly correlated with similar records in other sites. It is possible to find that different sites were affected by an El Niño event at approximately the same time, but we cannot be certain it was the same event at each site.

Examples of mollusks as indicators of El Niño events include both physical and geochemical markers of events. By studying a collection of *T. procerum* shells Sandweiss made in 1984 from individuals which survived the 1982-83 El Niño event, Rollins et al. (1986b) showed that macro- and microscopic changes occurred in shell growth during the months of maximum El Niño temperature. Working with the same collection of *T. procerum*, Andrus et al. (2005) recorded trends in the radiocarbon reservoir relative to stable isotopes of oxygen during El Niño, providing insight into marine upwelling. Also using the 1984 collection, Perez-Huerta et al. (2013) found geochemical changes associated with the El Niño event in *Trachycardium procerum*, a species that survives El Niño water temperature changes. Sandweiss (1996) documented the replacement of sand-dwelling, subtidal *Mesodesma* clams (which are decimated by El Niño) by the rock-dwelling intertidal mussels *Semimytilus algosus* and *Perumytilus purpuratus* (which are less impacted by El Niño) at the Late Preceramic site of El Paraíso just north of Lima. He interpreted this cyclical replacement as the result of El Niño impacts on available mollusks and further noted that when *Mesodesma* first returned in the stratigraphic sequence, the average size was unusually small, as though the population had recently begun from larvae, as would be expected in the wake of El Niño. The occasional presence of tropical mollusks in sites dominated by cool water species likely reflects temporary changes associated with strong El Niño events, as shown by Elera et al. (1992) for the north coast Formative site of Puémape. We have already mentioned Andrus et al.'s (2002) work on the geochemistry of fish otoliths, which can also be used to identify specific events. Recently, Caramanica et al. (2018) studied microbotanical remains from one of the stratigraphic columns at El Paraíso from which Sandweiss analyzed the mollusks. In Level G, they found indicators of El Niño-related florescence of the local plant community. In the same pit, Sandweiss found a minimum presence of *Mesodesma* just below, in Level H. This may reflect a faster effect of El Niño on mollusks than on plant communities; further research is needed.

El Niño-related erosion channels and flood deposits have been found in many sites. A good example of El Niño flood deposits is the Huaca Cortada, which is part of the Formative site of Caballo Muerto in the Moche Valley (Nesbitt 2016). There, Nesbitt dated pre-construction El Niño-related flood deposits to 3550-3400 cal BP; found three events during mound use, dated to 3550/3400 to 3050/2950 cal BP; and found a further deposit at site termination dated to 2950-2850 cal BP. The latter date is just when we have found evidence for a rapid increase in El Niño frequency. A case study of erosion channels comes from Ana Cecilia Mauricio's (2018) work at Huaca 20, an Early Intermediate Period mound in the Maranga Complex in Lima, which she discusses elsewhere in this volume.

El Niño in Peruvian archaeology–An Historical Perspective

Although El Niño must have been recognized by fishing communities of the Peruvian coast whenever it occurred and recurred, it was only discovered scientifically at the end of the 19th century (Eguiguren 1894). After the 1925 event, El Niño became better known to scientists globally, in part as the result of pioneering studies by Robert Cushman Murphy, Curator of Birds at the American Museum of Natural History in New York City, who was on a boat off northern Peru when the event began. Murphy started taking measurements immediately (Murphy 1926), and his data are still used by climatologists studying El Niño (e.g., Takahashi and Martínez 2019). Scientific study of ENSO has increased exponentially over subsequent decades, with many advances in understanding what causes ENSO events to happen, the different flavors (versions) of ENSO, the global teleconnections of ENSO, and more. We do not have the space here to summarize current understanding of ENSO beyond what we covered in the previous section; from here forward, we focus on the archaeology of El Niño. The number of archaeological studies about the impacts of El Niño have greatly expanded. In this summary, we largely focus on our own work. Readers are encouraged to delve into the many investigations of colleagues.

Archaeologists were late in their attention to the phenomenon. To our knowledge, the first Andean archaeologist to mention El Niño was James B. Richardson III in his 1969 dissertation. Richardson found Thermally Anomalous Mollusk Assemblages (TAMAs) in early archaeological sites in the Talara region of far northern Peru and recognized they might reflect a time when El Niño operated differently than today. This was the start to our first trend in El Niño archaeology (Using archaeological remains to improve understanding of when and how often El Niño occurred).

The next year, Mary Hrones Parsons (1970) published an article on "Preceramic Subsistence on the Peruvian Coast" in which El Niño played an important role. As she wrote in the abstract: "The phenomenon of the periodic El Niño Countercurrent and its drastic effects on both sea and land resources are discussed in detail…Vital problems concerning human adaptation to the coastal niche in preceramic times are stressed". El Niño as a disaster and as a force in human life, our second trend in El Niño archaeology (Studying El Niño's human impacts), had now begun.

Trend 1: Using Archaeological Remains to Improve Understanding of when and how often El Niño Occurred

Michael E. Moseley played a major role in archaeological studies of El Niño on the Peruvian coast, beginning in the early 1970s (e.g., Moseley 1975; Nials et al. 1979; Moseley et al. 1981). Moseley and his colleagues identified and studied many of the ways that El Niño events can be destructive. Later, he pioneered the concept of "convergent catastrophes" for the Andes, looking at the synergies between processes such as El Niño, tectonism, and eolian sand transport and at their effects on agriculture and other aspects of ancient life on the Peruvian coast (e.g., Moseley 1999; Moseley et al. 1992; Moseley and Richardson 1992; Satterlee et al. 2000). Some of the scenarios that Moseley and his colleagues outline (especially for the Miraflores Event north of Ilo, Peru; Satterlee at al. 2006) are truly frightening and remind us that El Niño can be devastating despite adaptation and mitigation strategies.

Cobble-dominated in 1980, Moseley sent Sandweiss to investigate the Santa beach ridges. This resulted in Sandweiss's hypothesis of beach ridge formation: a synergistic activity involving the production of loose sediment on unvegetated coastal hillslopes, transport of that sediment into the Santa River and then to the coast by torrential El Niño rainfall, with final littoral northward distribution and separation of sediment to form ridges (Sandweiss 1986). Moseley et al. (1992) used sequential remote sensing imagery to confirm this sequence in recent times. Additionally, they noted the expected sand component of the cobble-dominated Santa ridges are largely missing. Moseley et al. suggested that a portion of the sand moved inland in dune fields, which still traverse the region north of the Santa River as far as the Chao River. Following early work by Richardson (1983), Sandweiss and colleagues later studied the Chira, Piura, and Colán beach ridges on the far north coast of Peru using remote sensing and GIS (Shafer Rogers et al. 2004; Belknap and Sandweiss 2014). An El Niño involvement is also supported for those ridges. In the case of Colán, the source of the sediment creating the ridges is not a river with headwaters in the highlands, but instead is the arroyos in a cliff to the east of the ridges. The only time there is flowing water to move sediment through the arroyos is during El Niño rainfall, so the Colán ridges could only form during El Niño events.

When Moseley sent Sandweiss to the Santa ridges in 1980, he also instructed him to visit David Wilson in Santa. Wilson was then doing a survey of the Santa Valley for his University of Michigan dissertation (later published as Wilson 1988). Wilson told Sandweiss about some preceramic shell middens along the shores of an ancient beach to the east (inland) of the beach ridges and suggested a visit. These sites contained mollusk shells different from those normally found in Peruvian coastal sites. Unfamiliar with this fauna, Sandweiss asked IMARPE (Instituto de Mar del Perú) malacologist Violeta Valdiviezo for her help in identification. When Sandweiss returned to IMARPE for the results, Valdiviezo asked what he had been doing in Ecuador, since the shells were all warm water species found in Ecuador and not in Peru–in other words, they were a TAMA. He explained that they were from an archaeological site near the Santa River. Something odd was going on.

A few months later, Moseley introduced Sandweiss to three visitors from the University of Pittsburgh: James B. Richardson III, who had first mentioned the potential of archaeological remains to track ancient El Niños; Harold B. Rollins, a specialist in invertebrate paleoecology; and Jack Donahue, a sedimentary geologist who later founded the journal *Geoarchaeology*. Moseley sent Sandweiss with the visitors to show them the sites with the unusual mollusks. There, they found the same warm water species in life position in the paleobeach near one of the sites. They also visited several preceramic sites in the Salinas de Chao, just north of the Santa beach ridges, where all the shells observed were the cool water species normally found in Peruvian coastal sites. Sitting in the bar of the (then) Hotel de Turistas in Chimbote that night, the group discussed possible explanations for this distribution of molluscan fauna, and finally decided that the sites had to be of different ages (confirmed by multiple studies, e.g., Cárdenas 1977-1978; Sandweiss 1996). When the early, Santa paleobeach sites were occupied, climatic conditions must have been different enough that El Niño as we know it could not have been functioning, allowing warm water molluscs to thrive. This led to a preliminary statement of findings (Sandweiss et al. 1983) and a more robust paper on "The Birth of El Niño" (Rollins et al. 1986a). In these papers, we argued that for some period prior to about 5,000 14C BP (5800 cal BP), El Niño did not exist.

The radical hypothesis of a period without El Niño led to pushback, particularly by Thomas J. DeVries and Lisa E. Wells (1990), who argued that local conditions, not climate change, accounted for the presence of the warm water shells. In response, in 1991 Sandweiss excavated at the two main sites along the Santa paleobeach: the Ostra Base Camp and the Ostra Collecting Station, with the intent of recovering a collection of mollusks in situ along with other marine fauna that might give clues to climatic conditions. In particular, he hoped to find fish remains from offshore environments to establish regional conditions, not just those of a protected, warm water lagoon. The vertebrate collection from the Ostra sites went to zooarchaeologist Elizabeth J. Reitz for analysis.

In 1993, Sandweiss began a position at the University of Maine in the Anthropology Department and the Climate Change Institute. There, he soon met and began working closely with climate modeler Kirk A. Maasch and later geoarchaeologist Alice R. Kelley. In 1996, Sandweiss, Maasch, Reitz, Rollins, and Richardson carried out a meta-data analysis of all known preceramic sites from the north coast with available data on marine fish and mollusks. This led to a definitive statement that El Niño could not have functioned for several thousand years before 5,000 14C BP (5800 cal BP) (Sandweiss et al. 1996; see also Sandweiss et al. 1997 and 1998 for continuation of the debate with Wells, DeVries, and other others on the interpretation of the Ostra sites and climate change).

Reitz and Sandweiss published the faunal data from the Ostra Base Camp in 2001. The majority of fish species were warm water, but some were cold water. In 2002, C. Fred T. Andrus published the results of his isotopic studies of sea catfish *(Galeichthys peruvianus*) otoliths (Andrus et al. 2002) and found that at the Ostra Base Camp, summer SSTs (Sea Surface Temperatures) were as warm as a strong El Niño but in the winter, SSTs dropped as low as a modern winter. The average annual temperature was about 3˚C higher than today, but the amplitude of the seasonal cycle was much greater. These conditions are not representative of El Niño. Farther north at the Siches site, north of Talara, Andrus et al. also found a ~3˚C increased average annual temperature in mid-Holocene Sea catfish otoliths, but with a seasonal amplitude parallel to today but with a warmer offset. Mollusks from the Siches site indicate warmer conditions until after about 5800 cal BP. The vertebrate fauna provides a more detailed picture. Siches has three components: Amotape (~10,700–10,100 cal B.P.), Siches (~7900–6800 cal B.P.), and Honda (~5800–5200 cal B.P.). Compared to the region today, vertebrate fauna suggest that Amotape was warmer than present, Siches (where the otoliths analyzed by Andrus were found) was warmer still, and Honda had cooled to conditions similar to the region today (Reitz et al. 2019).

Also in 2001, Sandweiss and colleagues (2001) published a meta-data analysis of molluscan fauna from archaeological sites on the Peruvian coast. They found that two species extirpated during large magnitude El Niño events were absent on the north coast prior to 5800 cal BP, present from 5800 to 3200-2800 cal BP (now considered ca. 2900 cal BP) and absent again after that time. These species are the wedge clam *Mesodesma donacium* (called macha in Peru) and the large purple mussel *Choromytilus chorus* (called choro zapato in Peru). The best explanation for the disappearance of *Mesodesma* and *Choromytilus* after 2900 cal BP is that El Niño increased in frequency, with a recurrence interval too short for these mollusks to recolonize the territory where warm El Niño conditions caused extensive mortality. In their place, the most common species became the small surf clam *Donax obesulus* (variously called marucha, palabrita, and other names in Peru). *Donax* recovers quickly after El Niño events.

Based on research from 1980 to the early 2000s, Sandweiss and colleagues (2007, 2020a; Sandweiss 2003, inter alia) proposed the following sequence for Holocene El Niño frequency on the Peruvian coast:

-Before ~9000/8000 cal BP, El Niño was present in Peru but of unknown frequency.
-From ~9000/8000 to 5800 cal BP, El Niño was absent or very different from today.
-At 5800 cal BP, El Niño returned but at low frequencies, perhaps once or twice a century.
-At ~2900 cal BP, El Niño frequency increased to perhaps once or twice a decade and then fluctuated around the modern frequency.

In 2014, Matthieu Carré and colleagues published a study of Holocene El Niño frequency based on geochemical analyses of Mesodesma from coastal Peruvian archaeological sites at and south of ~12°S. They found that “ENSO variance was close to the modern level in the early Holocene and severely damped ~4– 5 ka. In addition, ENSO variability was skewed toward cold events along south coastal Peru 6.7–7.5 ka owing to a shift of warm anomalies toward the Central Pacific. The modern ENSO regime was established ~3–4.5 ka” (Carré et al. 2014:1045). As we have pointed out (Sandweiss et al. 2020a), their interpretation of Early and Late Holocene El Niño frequency for the central and southern coast does not differ significantly from our reconstruction for the coast north of 12°S, although we hypothesize a more abrupt transition just after 3.0 ka. For the early Middle Holocene, Carré et al. (2014) see cool events related to CP-EN warming in the central Pacific, while we see warming on the north coast of Peru. Our reconstruction of El Niño history agrees with Carré et al. in that the ENSO signal in the late Middle Holocene was diminished compared to later. However, we believe a diminished El Niño started earlier and lasted longer on the north coast than on the central and south coast (see Figure 2 in Sandweiss et al. 2020a). It is possible that north of Lima, COA events returned before EP-EN events, so that south of Lima an El Niño signal isn't present until later. We thus suggest that both records may be correct for their respective sections of the coast, and we point out that 12˚S represents a major climatic boundary on the Peruvian coast (Sandweiss et al. 2020a; also, Sandweiss et al. 1997, inter alia).

Trend 2: Studying El Niño's Human Impacts

Since 1970, archaeologists working on the coast of Peru have been concerned with the effects of El Niño on coastal societies. At first, El Niño was viewed largely as a disaster with the potential to precipitate social change, from collapse to increased complexity (see Van Buren 2001). Over time and following Van Buren's prescient critique, archaeologists have come to see that ancient Andean people were often resilient in the face of devastating events, such as El Niño. This helps explain our attempted reconstruction of long-term demographic trends on the Peruvian coast: Sandweiss and Quilter (2012) used Rick's (1987) radiocarbon date-based estimate of Preceramic population trends coupled with Wilson's (1988) ceramic age estimates from construction volume in the Santa Valley and Cook's (1981) demographic analysis of early Colonial records to roughly estimate population trends across time on the Peruvian coast and compare them to reconstructed El Niño frequency. Sandweiss and Quilter (2012) found that even as El Niño increased in frequency at 5800 cal BP and again at ca. 3000 cal BP, population also increased. Data from Goldberg et al.'s (2016) analysis of a large dataset of radiocarbon dates from 14,000 to 2000 cal BP does not change this picture significantly. The only true demographic disaster was the Spanish Conquest. Cook (1981) estimated that in the 100 years beginning in 1520 CE, just before the Conquest, north coast population decreased by a factor of 12:1. This had nothing to do with El Niño or any other "natural disaster".

Parsons (1970) understood El Niño as a subsistence disaster from the perspective of marine resources but noted that during these events, the desert and especially the lomas flourished (see Cano et al. 1999 and Tovar et al. 2018 for botanical confirmation of the anecdotal data used by Parsons). However, Parsons did not consider the effects of torrential El Niño rainfall on the irrigation systems that became critical to coastal subsistence systems of the last 4000 or more years. To be fair, her focus was on "the subsistence patterns of the groups of sedentary or semi-sedentary coastal dwellers" dated between 5450 and 3450 14C BP, which is approximately 6200 to 3700 cal BP, but also when El Niño was absent to rare. Like Parsons, in his critique of Moseley's

(1975) Maritime Foundations of Andean Civilization hypothesis, David Wilson (1981) also uses El Niño to set lean periods for maritime subsistence systems, but does not consider the effects of El Niño flooding on terrestrial agricultural systems. Indeed, Wilson proposed that maize was the subsistence base for the emerging complex societies of the Late Preceramic Period, but although maize has been found at coastal monumental sites of this period, it is rare and does not appear to be an important component of Late Preceramic diet.

Michael Moseley was one of the most important and prolific archaeologists writing on El Niño in Peruvian archaeology. Influenced by accounts of the devastation from the 1925 El Niño event, he labeled El Niño as "an agent of radical environmental alteration" and wrote that "El Niño perturbations and Andean tectonics have produced major crises in the twentieth century. Yet their combination and long-term interplay over the millennia preceding scientific observation have been far more dramatic and devastating" (Moseley 1983: 429). This was a theme in his work over much of his career, both in the field and in a host of publications. Indeed, Moseley's influence, direct assistance, and introduction to Rollins and Richardson is what led Sandweiss to study ancient El Niños. Moseley recognized that climatic and environmental events are linked and can act in synergy. For the Andes, the two most significant natural perturbations are tectonic activity and El Niño. Moseley led the way in looking at how they interacted and the consequences for humans inhabiting this region. Eventually, he came to refer to this process as "convergent catastrophes" (e.g., Moseley 1999).

Several examples of Moseley's convergent catastrophes approach illustrate this influential methodology. In 1992, Moseley and Richardson published a short piece in Archaeology called "Doomed by Disaster". Here, they drew on Moseley et al.'s (1992) remote sensing study of beach ridge formation north of the Santa River. That work confirmed Sandweiss's (1986) hypothesis of the interplay between tectonic activity, El Niño rainfall, and longshore processes, while adding the critical element of windblown sand moving inland on the constant onshore winds. Moseley and Richardson (1992) made the controversial suggestion that sand sheets blanketed the Moche capital on the south side of the Moche valley and caused the side to be abandoned.

In 2000, Dennis Satterlee and colleagues published a study of convergent catastrophes in the Miraflores Quebrada to the north of Ilo on Peru's south coast. They tracked the synergistic effects of drought followed by torrential El Niño rainfall and consequent flooding; the resulting picture, supported by field data, is sobering. They argue that subsequent "transformation of the [regional] subsistence and settlement patterns was a response to 'convergent catastrophes'"(Satterlee et al. 2000: 96).

From 2007 to 2009, Ruth Shady, Moseley, David Keefer, Charles Ortloff, and Sandweiss worked on the question of the abandonment of the Supe and adjacent valleys of the north central coast (also called the Norte Chico) at the end of the Late Preceramic Period (Sandweiss et al. 2009). There, too, convergent catastrophes seemed to be involved. The team found evidence of earthquakes late in the history of the Caral Civilization monumental sites, followed by sand incursion, lower quality reconstruction, and finally abandonment. Along the coast, a 100 km long barrier formed across the front of the north central coast valleys, perhaps fed by debris loosened by earthquakes and carried to the shore by torrential El Niño rainfall. The sand component then blown inland by the constant onshore winds made coastal agriculture less productive. Although not all the monumental sites were actually abandoned at the same time (Leclerc 2022), most aspects of this model still apply.

Sandweiss (1996) described incised stone pebbles from the Ostra Base Camp, a mid-Holocene site with evidence for significant climate change. The only other known provenience for these distinctive stones is the Ostra Collecting Station, a contemporary site on the same paleobeach as the Base Camp. However, similar but more complex carved stones are known from Valdivia sites on the south coast of Ecuador, which date immediately after the Ostra sites. These are the Palmar series stone figurines (Meggers et al. 1965). Sandweiss (1996: 48) suggests that the incised stones "represent some form of northwestern Andean cultural interaction in the Middle Preceramic period" that may reflect a time of shared environment between the coasts of southern Ecuador and northern Peru.

In a paper that was ahead of its time, Jerry Moore (1991) looked at how pre-contact coastal mollusk collectors in the Casma Valley may have responded to El Niño. Moore (p. 27) noted that (in 1991) "there are few archaeological data about the nature of cultural responses to a specific ENSO event" and called on archaeologists to do this work. Moore's paper was followed a decade later by Van Buren's critique of the archaeology of natural disasters in Peru, with El Niño as the main focus. Drawing on geography and the "new ecologies", Van Buren (2001: 129) asked "How, then, should natural disasters be incorporated into archaeological thinking about social change?". Since this call to action, archaeologists concerned with El Niño have increasingly taken on this challenge and focused on means of resilience in the face of what would be disastrous without proper knowledge and preparation. Following are a few examples.

At the same time Van Buren published her 2001 critique, Sandweiss et al. (2001) outlined evidence for a rapid increase in El Niño frequency about 3200/2800 cal BP. Although the focus of this paper was on EN frequency change, they noted that "[t]echnology, history, cultural practices, religion, perception, and individual and group idiosyncrasies can all affect the way a society and its members respond to change" before asserting that "radical environmental change requires some response from the people who experience it" (p. 605). As evidence of a cultural response to increasing El Niño frequency, they drew on co-author Richard Burger's work at the Initial Period site of Manchay Bajo in the Lurín Valley just south of Lima (see also Burger 2003). There, Burger found a large wall built on two sides of the monumental structures and at the base of two quebradas that carry debris flows during El Niño rainfall. Had the walls been intended for defense from humans, they would have surrounded the site. Rather, they seem intended to protect the site from El Niño-created debris flows. Most Initial Period sites on the coast of Peru were abandoned when El Niño frequency suddenly increased, but Manchay Bajo lasted about a century longer.

We have already mentioned Mauricio's (2018) work at Huaca 20. Along with tracking erosional channels, she also addresses the human responses to the events. Readers are directed to her paper in this volume.

Caramanica et al. (2020) published a groundbreaking study of resilience agriculture on the north side of the Chicama Valley over the last 2000 years. They found a series of specially designed structures built to take advantage of runoff water from El Niño rainfall while the normal irrigation system was disrupted. It would be interesting to see if these structures extend several centuries earlier, to the time of increased El Niño frequency early in the first millennium BCE.

In 2022, Sandweiss and Maasch published a study of site abandonment and El Niño in the Lambayeque Valley over the last eight centuries of prehispanic control: Pampa Grande, Batán Grande, and Túcume. In each case, the sites were the most important of their epoch, and each was abandoned with the principal temples burned before the next site was constructed and rose to power. However, independent climate records only show significant El Niño activity just prior to the abandonment and burning of Pampa Grande, at or shortly after 750 CE. The final abandonment and burning took place at Túcume and is tied to the Spanish Conquest. Even if El Niño had something to do with the end of Pampa Grande, there are two important lessons from this study:

1)We need to be aware of equifinality and use it to recognize that different stressors may trigger the same, culturally dictated response.

2) At no time was the Lambayeque Valley abandoned–sites rose and fell, but people found solutions that kept them living successfully in the same region.

Lorenzo Huertas published an important account of an early Colonial El Niño (Alcocer 1987[1580]). This document consists of responses to questionnaires about the 1578 El Niño event, the first large magnitude El Niño after the Spanish Conquest. Much had changed in the nearly half century since the Conquest as a result of depopulation, concentration of people in settlements called reducciones, and other Spanish impositions. Nevertheless, people would still have been alive who had been born before the arrival of the Spaniards, and much useful information on the indigenous Andean response to El Niño events can be gleaned from this fascinating document. Witnesses were called by either caciques or encomenderos to respond to different versions of the same questions. All identified themselves in some detail, so we know who was speaking in each case (Copson and Sandweiss 1999). The reader is referred to the paper by Leclerc and Landázuri in this volume for more information on this document.

St. Amand et al. (in review) write about adaptation and resilience in the face of El Niño events across time on the Peruvian north coast. Inspired in part by the Alcocer document about El Niño in early Colonial Lambayeque, they also considered the role of traditional ecological knowledge (TEK) in El Niño resilience. Although difficult to uncover archaeologically, repeated El Niño resilience strategies can be discerned in the archaeological record, and may give further insight into this topic, allowing a direct historical approach for at least for the latest pre-contact societies.

As an indicator of archaeologists' growing focus on incorporating "natural disasters… into archaeological thinking about social change," as Van Buren (2001: 129) challenges us to do, at the 2022 Annual Meeting of the Society for American Archaeology, Sandweiss organized a session on "El Niño and the Archaeology of Resilience on the Peruvian Coast". Table 2 lists the participants and their paper titles as an indication of where the field is going.

Table 2.
Participants in "El Niño and the Archaeology of Resilience on the Peruvian Coast", SAA Annual Meeting, Chicago IL USA, 2022.

Ana Mauricio, Alice Kelley, Daniel Sandweiss, Francisco Rumiche and Rolf Grieseler	El Niño and the Origins of Adobes in the Americas
Alice Kelley, Ana Mauricio and Daniel Sandweiss	Building for Protection: Check Dams and El Niño in the Chao Valley, Peru
Rachel Johnson and Jason Nesbitt	Resilience and Risk in the Placement of Initial Period Coastal Centers
Paul Roscoe	Resilience and Vulnerability at the End of the Initial Period in Ancient Peru
Gabriel Prieto	Evidence of ENSO-like Events during the Late Early Horizon (400–200 cal BC) in Huanchaco, North Coast of Peru
Ari Caramanica	Reexamining Small-Scale El Niño Event–Based Farming on the North Coast of Peru
Samuel Martin, John Shaw, Chris Cathcart, Marc Marino and Cory Hughes	The Simulation in the Sandbox: Modeling ENSO River Channel Behavior Using Physical Experiments
Benjamin Vining, Daniel Contreras and Aubrey Hillman	Archaeological and Ecological Evidence for El Niño-Driven Expansion of Agroecological Niches on Peru's North Coast
Elizabeth Leclerc	A River Runs through It: Basin-wide Perspectives on ENSO's Hydrological Risks and Opportunities
Frankie St. Amand, Elizabeth Leclerc, Emily Blackwood and Heather Landázuri	Getting into (and out of) Hot Water: Climate Hazards, Resiliency, and ENSO in the Archaeological Record
Heather Landázuri and Daniel Sandweiss	Avenidas de Agua: Indigenous Resilience during the 1578 El Niño
Mary Van Buren	Discussant

Concluding Remarks

What still needs to be done? The short answer is that the study of El Niño in Peruvian archaeology is still in its infancy–there is a lot left to do. We offer some brief suggestions while recognizing that there will be new kinds of studies, with new techniques and theories that surpass anything we can think of, and that is how it should be.

First, continue to develop El Niño chronologies for the Peruvian coast. This will require both more analyses using existing methods and developing or adapting new methods to produce new data. Improving El Niño chronologies will help archaeologists investigate human responses to these events. By providing more robust data about the past against which to test models, this work will also aid paleoclimatologists and climate modelers in improving understanding of past climate and in predicting future climate change.

Second, continue the search for proxy records of Central Pacific El Niño (CP-EN) relevant to precipitation patterns in Peru. A 50% reduction in water flow to the coast (Sandweiss 2019) would be a significant stressor for irrigation-based societies. Prior studies have often suggested drought as a cause or partial cause of societal change in the ancient Andes (e.g., Shimada et al. 1991; Satterlee et al. 2000). It is also important to find proxy records for La Niña, given its consequences for respiratory health.

Third, continue uncovering technologies of the past that can be deployed today, particularly those available at low cost (they would have been done without machines or draft animals), and advocate for their use now. The field systems discovered by Caramanica et al. (2020) in Chicama are a good example.

Fourth, continue to increase our knowledge of pre-contact TEK. Successful adaptations to El Niño cannot have been only technological; there had to be appropriate social mechanisms to ensure endurance in the face of El Niño stressors. If we can find them, they will inform current attempts to mitigate events. The human and financial toll of 20th and 21st century El Niño/Coastal El Niño events (e.g., RPP 2017 and Caramanica 2018) suggest contemporary society is not optimizing its response.

"[R]adical environmental change requires some response from the people who experience it" (Sandweiss et al. 2001:605). Resilient adaptations are among possible responses. Because the archaeological record of pre-contact Peru shows overwhelming success in surviving and thriving despite El Niño events and even increases in El Niño frequency (Sandweiss and Quilter 2012), we urgently need to improve our understanding of all aspects of human ecodynamics (Fitzhugh et al 2019) related to El Niño and other flavors of ENSO, and to communicate our findings more successfully to communities and governments.

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