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"READING" THE SHELLS: DANIEL H. SANDWEISS AND THE RECASTING OF ENSO AS A FEATURE OF COASTAL PERUVIAN ENVIRONMENTS

"LEYENDO" LOS MOLUSCOS: DANIEL H. SANDWEISS Y LA REFORMULACION DEL ENOS COMO UN DISTINTIVO DE LOS AMBIENTES COSTEROS PERUANOS

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Abstract

Human-environment dynamics in coastal Peru are fundamentally tied to the El Niño Southern Oscillation (ENSO) phenomena. The El Niño phase of the ENSO cycle can manifest in multiple ways, including heavy rainfall and flash floods, overbank flooding along rivers, and mass death events among marine fauna, which archaeologists have hypothesized catalyzed socio-political shifts in the pre-Hispanic past. However, establishing secure archaeological sequences of human interaction with El Niño activity is a major obstacle to research. Daniel H. Sandweiss and colleagues' holistic approach to mollusk analysis represented a seminal innovation in human-environment records. More importantly, their interdisciplinary work combining mollusk with geo- and archaeological records, arguably caused a phase-change in research around ENSO and El Niño in the pre-Hispanic past: while previous research focused on event magnitude as a driver of social change, Sandweiss' approach to the long-term life cycle of ENSO, recast the El Niño phenomenon as a feature of the natural environment, opening the way to further complicate monocausal models and move toward multi-faceted interpretations of its role in society.

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Resumen

La dinámica entre los humanos y el medio ambiente en la costa peruana está vinculada fundamentalmente al fenómeno de El Niño Oscilación del Sur (ENOS). La fase de El Niño del ciclo ENOS puede manifestarse de múltiples maneras, incluyendo fuertes lluvias e inundaciones repentinas, desbordamientos de ríos, y eventos de muerte masiva de fauna marina; los arqueólogos han propuesto que tales impactos podrían haber catalizado cambios sociopolíticos en el pasado prehispánico. Sin embargo, establecer secuencias arqueológicas seguras de la interacción humana con actividad de El Niño es un gran obstáculo para la investigación. El enfoque holístico de Daniel H. Sandweiss y sus colegas a los registros de moluscos representó una innovación seminal en el análisis de la relación entre los humanos y el medio ambiente. Más importante aún, su trabajo interdisciplinario combinando moluscos con registros geo y arqueológicos, posiblemente causó un cambio de fase en la investigación en torno al ENOS y El Niño en el pasado prehispánico: mientras que la investigación se ha centrado en la magnitud de los eventos como un motor del cambio social, el enfoque de Sandweiss sobre el ciclo de vida a largo plazo de ENOS, reformuló el concepto del fenómeno de El Niño como una distintivo del medio ambiente natural, abriendo el camino para complicar aún más modelos monocausales y avanzar hacia interpretaciones multifacéticas de su papel en la sociedad.

Palabras clave: El Niño Oscilación del Sur, moluscos, dinámicas humano-medioambiente, Holoceno, desastres, manejo de inundaciones, agricultura, arqueología, costa de Perú.

> "…walls and ceilings as well as foundations having become thoroughly soaked, causing them to disintegrate in much the same manner as a lump of sugar does when placed in liquid…" (Robert Cushman Murphy 1926: 44).

Robert Cushman Murphy's account of the 1925 El Niño event catapulted the phenomenon to international scientific attention (Cushman 2004; Murphy 1926). It was soon cast as a "disaster" in the emerging field of catastrophe studies, and that framework has come to dominate much of the research on pre-Hispanic human-El Niño interactions on the north coast of Peru (Bawden 2000; Prince 1968). However, the hazards that result from El Niño Southern Oscillation or ENSO, are part of a much broader pattern of oceanic-atmospheric dynamics, whose timing, spatial extent, and intensity play an important role in coastal landscape formation, and the availability of crucial resources (Anderson 2007). This paper outlines the history of archaeological research around ENSO and finds that while one school of thought has approached El Niño as a 'bug' of a fragile social-ecological system, another school of thought, led by Daniel H. Sandweiss, opened the way to viewing ENSO as a feature of that system. It was Sandweiss’ innovative use of archaeological Thermally Anomalous Molluscan Assemblages (TAMA) as climate indicators that exposed ENSO as a malleable component of the early and middle Holocene environment, overturning prevailing assumptions that the coastal environment was a static and passive background to Preceramic Period sociopolitical development. Sandweiss’ commitment to interdisciplinary work, collaborating throughout his career with climate, geo-, and atmospheric scientists, has not only resulted in a more comprehensive, nuanced understanding of the El Niño phenomenon, including its relationship to broader patterns of climate change, but has also shown that an archaeological approach is uniquely qualified to examine both long-term processes and events in human-environment histories.

The Dynamics and Variance of ENSO

El Niño Southern Oscillation (ENSO) describes shifting pressure cells across the western, central, and eastern Pacific. The ‘Oscillation’ of pressure conditions occurs in three phases: La Niña, Neutral, and El Niño. La Niña describes strong easterly winds and cooler sea surface temperatures (SSTs), which typically result in dryer-than-normal conditions on the north coast. The Neutral phase in the eastern Pacific is characterized by higher-pressure conditions, high sea levels, trade winds, and a shallow boundary between the warm SSTs and cold water, also known as the thermocline, resulting in almost no precipitation on the Peruvian coast (Maasch 2008: 43). Neutral conditions, combined with the rain shadow effect caused by the Andes mountains, and the very cold, near-surface waters along the coast, result in extreme aridity. These cold waters, known as the Humboldt Current, support some of the world’s most productive fisheries, but also severely limit precipitation on the coastal plain.

During an El Niño, sea level pressure (SLP) in the eastern Pacific lowers, causing trade winds to weaken, and occasionally reverse, and the thermocline to deepen. A deeper thermocline results in diminished upwelling and an increase in SSTs along the coast of Peru and Ecuador, which can have devastating effects on marine life. During an El Niño event, SSTs can rise 8°C along the north coast of Peru, resulting in mass death events up and down the trophic chain: from plankton and mollusks to dolphins and sea lions (L. a. J. M. Ortlieb 1993; 1995).

Strong El Niño conditions have global affects (teleconnections): warm currents can reach the California coast and impact regions from the Gulf of Alaska to Central America to the southeastern United States (Caviedes 1984; Maasch 2008; Quinn 1993: 48-54), with some studies identifying sensitive correlations between the sea level in the Gulf of Panama and SST in Puerto Chicama, Peru (Glynn 1988:313). Across the broader Andean region, precipitation in neighboring countries such as Paraguay, Brazil, and Chile, increases, while the Peruvian altiplano experiences drought (Caviedes 1984; Quinn 1987; Tapley 1990). The most recognizable results of strong El Niño conditions are heavy rainfall and flooding that manifest along the coasts of Peru and Ecuador, resulting in events such as that described by Murphy (1926) in 1925.

An El Niño's abnormally warm summer current results in rainfall on the otherwise arid coast. The rainfall often triggers flash floods or debris flows (huaycos) in normally dry drainages (quebradas) along the base of the Andean foothills, and causes river volumes to rapidly increase, leading to overbank flow. For example, daily coastal river discharge during March of a neutral year averages 74.02m^3s^{-1} (ONERN 1973); in March 1925, the Chicama River reached a discharge of 530m^3s^{-1} (Takahashi 2017).

Despite the dramatic environmental and weather changes that El Niño conditions produce, the events themselves are notoriously difficult to predict. They vary in their location, intensity, and frequency over time (Fontugne 1999; Glynn 1988:314; Moy 2002). For example, the scale of flooding depends heavily on the size and shape of the catchment where precipitation occurs (Billman 2008; Huckleberry 2003). At the regional scale, the south coast rarely experiences El Niño events; instead, heavy rainfall is concentrated on the north coast, from Piura to the Virú Valley, where orographic characteristics[1] and proximity to the Equator, result in more intense precipitation (Beresford-Jones 2009:22-23; Magilligan 2008:15; Waylen 1986). Even within the north coast region, rainfall is not experienced evenly over the course of an event (Tapley 1990; Waylen 1986). Multiple accounts of El Niño events through time describe the remarkable circumscription of some events, with rainfall and flooding occurring in one valley and sunny skies prevailing in the neighboring valley.

El Niño floods, therefore, appear to have all the trappings of disasters: they can be destructive, appear with little warning, and they vary considerably from event to event (see Burton 1978). The archaeology of El Niño on the north coast of Peru has, in large part, centered on the societal consequences of such disasters, which, from a research design perspective, requires the challenging practice of matching evidence of change in social phenomena with records of climatic trends or events (Burger 1988; Donnan 1990; Fagan 1999; Moseley 1987, 1997, 1999; Moseley 1992; Nials 1979; Shimada 1991). Consequently, the data commonly targeted by research teams tend to favor large-scale El Niño events, or region-wide trends —more readily detected across multiple sites— and these records, when they can be recovered, each have their own strengths and weaknesses.

ENSO Records: an Issue of Scale

Records drawn from lake, marine, pollen, and glacial cores (McGlone 1992; Moy 2002; Rein 2007, 2005; Rodbell 1999; Shulmeister 1995; Thompson 1985, 1995; Thompson 1984), foramnifera (Koutavas 2012), and corals (Cobb 2003; Cobb 2013), point to large-scale and even global trends in Holocene ENSO activity. Dust and O isotopes, for example, indicate that the Andes experienced dry periods (possibly related to ENSO conditions on the coast) between 1720-1860; 1250-1310, and 570-610CE (Thompson et al. 1985). These records inform interpretations at the site-scale, but they lack the local precision to address the magnitude or location of an El Niño event and, cannot themselves link to archaeological evidence of a societal effect.

Historic and ethnohistoric records, on the other hand, do provide specificity on timing, damage, and even the immediate human response to events (Huertas Vallejos 1987; Ortlieb 2000; Quinn 1993; Quinn 1987). Combined with other sources, these data elucidate longer-term risk mitigation strategies or technological adaptations. However, although there are written records of major El Niño activity as early as 1578CE for the north coast of Peru, such data are not available for the pre-Hispanic past.

Geological data, such as mud deposits, slack water deposits, and evidence of large-magnitude events identified in beach ridge stratigraphy, also provide locality-scale data on a particular event or even separate pulses within a single event (Keefer 2003; Nials 1979; L. Ortlieb, Marc Fournier, and José Macharé 1993; Wells 1987, 1990). When they appear within an archaeological context, the possibility of dating these events increases. However, geomorphologists caution against interpreting larger-scale patterns or widespread effects from a depositional context (see Delle Rose 2022). Billman and Huckleberry’s (2008) work in the Moche and Chicama Valleys, identified diverse factors that can determine the scale of flooding, and therefore the size of deposition. In other words, rather than representing the magnitude of the event, stratigraphic evidence of flooding can more accurately reflect whether precipitation occurred in the middle or the lower valley, the size of the affected catchment, or the gradient of the ravine.

Thus, research into human-ENSO dynamics in the pre-Hispanic past has often confronted an intractable problem of scale: data are either too low-resolution or too high-resolution. Datasets that could reliably bridge these scales have proven challenging to identify. Daniel H. Sandweiss and colleagues, Harold Rollins and James Richardson, pioneered the use of malacological data to fill this gap.

Mollusks: Multidimensional Environmental Data

Archaeological molluscan assemblages provide a unique package of data. The shells themselves can indicate organism growth patterns, which point to favorable or unfavorable habitat conditions. Shell chemistry (O isotopes) reflects past changes in sea temperatures. The relative population of warm water-versus cold water adapted species capture El Niño dynamics or large-scale climate change (Sandweiss 1996; Sandweiss 2003). At the same time, when recovered from archaeological middens contexts, molluscan assemblages reflect human behavior, including diet preferences, adaptive strategies, tool-making, and symbolic practices. In habitation sites with long occupations, molluscan assemblages provide secure dates for changing environmental indicators and cultural variables over time. When multiple, geographically and chronologically disperse assemblages are combined, as Sandweiss and colleagues achieved over the course of several decades of work, long-term spatial patterns come into relief alongside site-scale events, creating a multi-dimensional record of human-environment dynamics (Anderson 2007; Andrus 2008; Maasch 2008; Reitz 2001; Rollins 1986; Sandweiss 2020, 1999, 2007, 2004, 2001; Sandweiss 1986; Sandweiss 1996; Sandweiss 2003, 1983; Sandweiss, Richardson, Reitz, Rollins, Maasch 1996).

In order to faithfully interpret both the human and the environmental data from pre-Hispanic malacological records, Sandweiss (1996) argues that the researcher much undertake a holistic understanding of the source site, context, and modern-day ecology. "Reading" shell middens means accounting for the selection and taphonomic biases of a given sample by contrasting the archaeological remains with the population variance in a natural assemblage (1996:130). However, the likelihood of finding a 'goldilocks' site with both intact shell middens and a natural record of shell deposition has been complicated by global sea level rise at the beginning of the Holocene, which flooded many early coastal shell processing sites.

The Ostra Complex was explored by Sandweiss in the early 1980s while he was working with Michael E. Moseley and David Wilson in the Santa Valley (Richardson 2008). The site is located adjacent to a paleo-shoreline, approximately 5km further inland than the modern-day shoreline (Sandweiss 1983:280); tectonic uplift saved the site from inundation during eustatic sea level rise in the early-mid Holocene. The site dates between 7150 and 6200 cal yr B.P. (Richardson 2008; Sandweiss 1996). Here, Sandweiss identified Thermally Anomalous Molluscan Assemblages (TAMA) in quantities previously unknown for this period, both in middens associated with human habitation and in the natural beach ridges. The comparison across the archaeological and naturally deposited records allowed Sandweiss and colleagues to conclude that the prevailing conditions in the Middle Preceramic Period (8800-5800 cal yr. B.P.) were approximately 4°C warmer than present, suggesting that the frontier of the cold Humboldt Current was likely further south at the time of Ostra occupation (Richardson 2008). These insights had major implications for the history of El Niño. First, they implied that if ENSO was active at the time, the manifestations of El Niño on the north coast would have been minimal because neutral SSTs were already warm; second, they suggested a significant change in ENSO regime occurred sometime after the Middle Preceramic, both in terms of space and the timing of Oscillation intervals.

Complementing the work at the Ostra Complex, Sandweiss and colleagues combined their archaeomalacological methodology with geoarchaeological methods across a range of preceramic coastal sites and found that El Niño activity was largely absent during the Middle Preceramic Period. Waters along the Peruvian coast cooled around 5800 cal yr B.P., leading to increased richness in coastal fisheries (Rollins 1986; Sandweiss 1999, 2004, 2001; Sandweiss 2003; Sandweiss, Richardson, Reitz, Rollins, Maasch 1996). After 5800 cal yr B.P., sea level stabilized and El Niño frequency, though intermittent, was detected approximately every century. By 3200 cal yr B.P., El Niño intervals increased to modern levels (every ~7-10 years).

The timing of increased El Niño oscillation activity coincided with the development of monumental ceremonial architecture at several Late Preceramic Period (3000-1700 cal BCE) sites (Quilter 1991; Quilter, and Ojeda E., Pearsall, Sandweiss, Jones and Wing 1991; Sandweiss 2001, 2009). The molluscan data supported the observations of Lanning (1963), Parsons (1970), and the 'Maritime Hypothesis' of Michael E. Moseley (1975), all of whom noted an increased exploitation of cold-water fisheries, and an inland migration of settlements during the Late Preceramic Period, though they attributed these changes to different social and environmental forces.

The correlation of more frequent El Niño activity with the emergence of monumentality on the coast challenges the hazard framework, which casts El Niño as a system aberration. Rather, Sandweiss' work paved the way for considering both the catastrophic and the fundamental aspects of this oceanic-atmospheric phenomenon for the environment of the north coast of Peru.

Sandweiss' history of shifting ENSO prevalence over the mid- to late Holocene, has since been confirmed again and again by non-archaeological climate data, demonstrating that archaeological proxies not only provide reliable environmental records, but they often directly link to spatial, chronological, and anthropological data (Leclerc 2023; Sandweiss 2020), creating an invaluable multi-dimensional data 'package'.

Recasting ENSO as a Feature of the Coastal Peruvian Environment

Sandweiss' seminal work established that ENSO has been a crucial component of coastal Peruvian ecology for millennia. As a result, new directions in human-environment research have centered on the various impacts of ENSO in the local environment. For example, Manners et al.'s (2007) work in the middle and upper Mocquegua River Valley demonstrated that, while El Niño events result in the immediate loss of arable land, its floodwaters also transport sediments to fan terraces, where new vegetation is later established (see Tote 2011). The mobilization of sediment by El Niño events triggers several extenuating effects: alluvium is periodically deposited on fan terraces, and, eventually, 'soil dust' from these terraces makes its way into surrounding desert plains or *pampas*. 'Peri-desert loess' or soil dust, enriches the hyper-arid soils of these pampas by contributing silt and clay, and increasing their capacity to support vegetation (Goudie 2006; Mächtle 2013; Noller 1993; Pye 2009:143). In fact, when El Niño rains combine with desert soils, the effects on plant communities are transformative.

The influx of El Niño water into desert environments results in blooming events with staggered appearances of first, herbaceous ground cover, followed by shrubs, and finally trees (Richter 2005:143-144). While the Neutral-year vegetative community in Peruvian deserts is typically composed of up to 25% plant cover, during the 1997/1998 El Niño event, in some areas, plant cover increased to 100 +/- 20% in just three months (143-144). Arid ecosystems are capable of responding quickly to pulses in precipitation because seed banks have built up over time (Holmgren 2001, 2006).

Finally, groundwater levels also are likely controlled by ENSO patterning. Magilligan et al. (2008) used isotopic signatures from groundwater samples to hypothesize that ancient springs were recharged after El Niño flood events in the pre-Hispanic past. In the Moquegua Valley, Tiwanaku canals were located near such springs, which were then tapped to carry water to marginal areas on the edges of the floodplain. The canals date to approximately 700-730CE coincident with a significant El Niño flood (28). Such evidence suggests that El Niño served a vital role in aquifer recharge, possibly allowing for agricultural expansion beyond the floodplain in the pre-Hispanic past (see also, Vining et al. 2022).

Implications for Research on pre-Hispanic Farming Systems

When El Niño is viewed through the lens of 'disaster,' farming infrastructure necessarily becomes a system vulnerability for north coastal societies (Moseley 1983; Van Buren 2001). But, modeling ENSO dynamics as a feature of the local environment creates avenues for re-interpreting farming systems as adaptive with important implications for models of socioeconomic development on the north coast. My own work in the Chicama Valley has drawn heavily from this framework, first established by Sandweiss, and while much work remains, more and more evidence is building to support the idea of ENSO-adapted farming infrastructure in the pre-Hispanic past (see also, Dillehay and kolata 2004).

The Pampa de Mocan, an abandoned pre-Hispanic (900BCE-1460CE) irrigated landscape located outside the Chicama Valley floodplain, features pre-Hispanic irrigation technology, including aqueducts and canals, but also opportunistic constructions that reflect El Niño water harvesting strategies (Caramanica 2022; Caramanica et al. 2020). The results from the Pampa de Mocan indicated that El Niño floodwaters were, periodically, a significant water resource; they further suggest that past coastal societies may have made large-scale investments in capturing and diverting floodwaters for agricultural purposes. Such infrastructure would logically be located along the foothills of the Andes, in or around the ravines or quebradas that transform into active flood channels during El Niño events.

Recent survey in the nearby San Jose Alto Quebrada of the Chicama Valley, just southeast of the Pampa de Mocan, identified several, large-scale features that date to 900-1460CE at the latest. Detailed mapping revealed they appeared to be 1) a canal and 2) a mounded feature, and both had unusual dimensions for irrigation works in the north coast context (**Figure 1**). In February-April of 2017 and 2023, my team and I had the chance to observe these archaeological features in the context of El Niño-like conditions. Drone photography collected just after the Yaku Cyclone event in 2023, indicates that while water was not dammed behind the mounded feature, it facilitated water storage in the upslope sediment, as evidenced by the concentration of dense vegetation (**Figure 2**). The nearby 'canal' also demonstrated signs of its function. The path of the canal indicates that this was likely built, not to deliver river water, but to deliver runoff floodwater from one ravine to another, potentially to backfill the secondary ravine for water storage in sandy sediments.

While more work remains to understand these features, it is possible that they were created to divert, impound, or spread El Niño floodwaters. Perhaps the best evidence to date to support this hypothesis, is the behavior of modern-day farmers. In summer 2023, our team observed farmers moving into the downslope areas of these features and excavating shaft wells for irrigation. Those wells are visible in new Google Earth imagery (**Figure 3**).

Including ENSO as a feature of the pre-Hispanic environment raises new and stimulating questions about the practices and even the origins of agriculture on the north coast of Peru, and across the broader Andean region (see Barnard 2017).

Figure 1. Quebrada San Jose, located just northeast of the modern town of Ascope. Two monumental features are visible in the vicinity of pre-Hispanic canals and a Late Intermediate period (900-1460CE) cemetery.

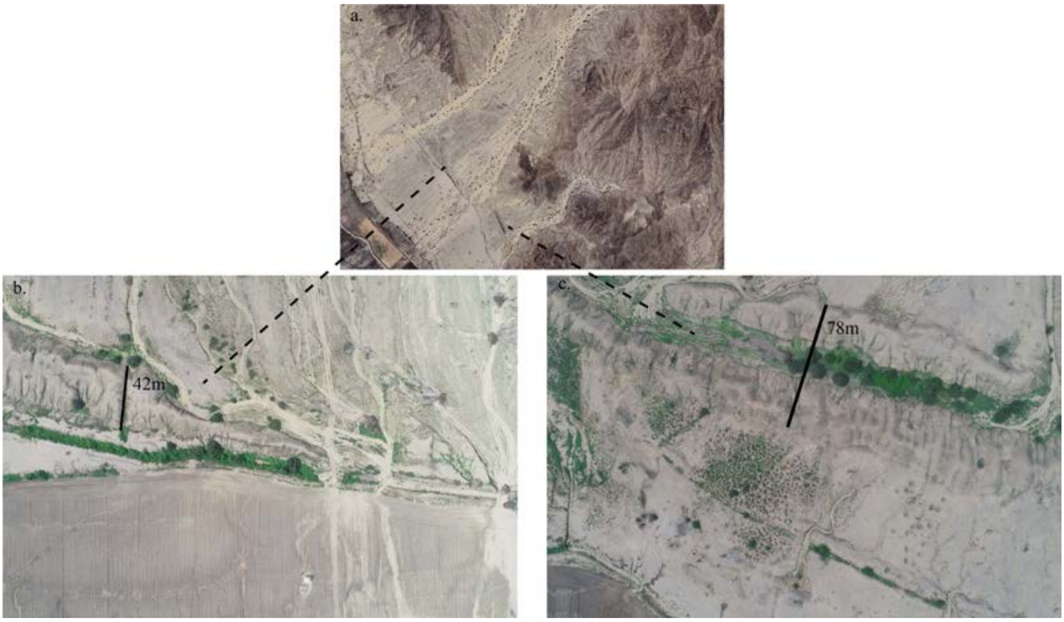

Figure 2. Google Earth Image (2024 CNES/Airbus) with detail of modern shaft wells located just downslope of the pre-Hispanic mounded feature in 2024.

Figure 3. a) Google Earth Imagery (2024 Airbus) of the San Jose Quebrada; b) Plan-view detail of the mounded earth feature taken with a drone in the months after the 2023 Yaku rain event.; c) Plan-view detail of the canal feature taken at the same time. Note density of vegetation around pre-Hispanic features compared to a year without precipitation, ie Airbus image.

Conclusion

The unevenness of ENSO’s effects across the region has posed scalar challenges to its detection in the pre-Hispanic past (Placzek 2001). Archaeological data in combination with natural records are uniquely capable of addressing the variability inherent in the El Niño phenomenon, capturing a range of environmental and human indicators (Rollins 1986; Sandweiss 2020, 2004; Sandweiss 1996; Sandweiss, Richardson, Reitz, Rollins, Maasch 1996). El Niño events can be catastrophic, but rainfall, floodwaters, and other manifestations of ENSO, have ‘positive’ effects on the desert coast landscape as well.

Discussion of El Niño and its effects is often couched in terms of hazard research, catastrophism, or collapse. Warm El Niño currents lead to mass deaths in fisheries, and floodwaters cause extensive erosion, breach irrigation infrastructure, and perhaps most destructive for local smallholders, flood agricultural fields. Secondary effects include diseases, rodents, insects, and food and water shortages. However, seminal work by Sandweiss and colleagues, has shifted the field by demonstrating that ENSO, and in particular, El Niño frequency, are integral components of the local environment, and have changed over time. Rather than a systems-based, human ecology framework, where ‘disaster’ has only transitory effects on ‘normal’ conditions (Erickson 1999; Moseley 1987; Van Buren 2001), ENSO can be modeled as embedded in a human-environment system (W. Balée 2006; Balée 2006; Erickson 2006; Hakansson 2014). As a result, more research is being directed at pre-Hispanic investments targeting the various impacts of El Niño and changing our understanding of human and environmental history of the north coast region.

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Notes

[1] Waylen and Caviedes 1986 find that the amount of basin area located on the coastal plain, as opposed to in higher altitudes (>1000m) can correlate to the amount of flooding that a given valley experiences (153).

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