# Collation, Correlation, and Causation in the Prehistory of Coastal Peru



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# SURVIVING SUDDEN ENVIRONMENTAL CHANGE

## ANSWERS FROM ARCHAEOLOGY

EDITED BY JAGO COOPER AND PAYSON SHEETS

# SURVIVING SUDDEN ENVIRONMENTAL CHANGE

## UNDERSTANDING HAZARDS, MITIGATING IMPACTS, AVOIDING DISASTERS


*Edited by*
Jago Cooper and Payson Sheets

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# Collation, Correlation, and Causation in the Prehistory of Coastal Peru

*Daniel H. Sandweiss and Jeffrey Quilter*

To the casual visitor and even many archaeologists, the mountains and deserts of Peru (figure 5.1) appear timeless and unchanging. Indeed, mountains are frequently metaphors for long-term stability and slow change: "how many years can a mountain exist, before it is washed to the sea?" asked Bob Dylan. So, too, the coastal strip shared by much of Chile and Peru hosts one of the driest deserts in the world (figure 5.2), which imbues the visitor with a sense of constancy. Regional archaeology features a great variety of unearthed artifacts made of perishable materials—wood, bone, shell, cloth—that would have disintegrated long ago in other environments. Subspecialties in scholarship have developed from the products of the dry, coastal environment: textile experts who study brightly colored, intricately woven textiles of coastal Peru, and biological anthropologists who can investigate ancient diseases and pathologies thanks to well-preserved human remains. But the apparent stability of the landscape of western South America belies a highly dynamic geological and biophysical terrain.

To address issues of prehistoric human ecodynamics in this extraordinary place, we begin by describing the region. We then consider in general terms the methodological and epistemological challenges to understanding collation, correlation, and causation in the archaeological record, with particular reference to human-environment interaction. We conclude with a detailed case


5.1. *Map of Peru. Map by Daniel H. Sandweiss.*

study from coastal Peru (a medium-term perspective) and a longer-term perspective on millennial-scale trends in risk, population, and complexity in this extreme environment.

## THE CENTRAL ANDEAN COAST

The central Andean coast (figure 5.1) is subject to significant natural disasters that tend to recur frequently but without a predictable periodicity. The Andes are located on a subducting plate margin (the oceanic Nazca Plate is sliding

**5.2.** *Typical dunes on the Peruvian coast. Photo by Daniel H. Sandweiss.*

under the continental South American Plate), so the region experiences frequent seismic activity and volcanism. Earthquakes, volcanic eruptions, and the tsunamis sometimes associated with seismic activity have a devastating impact not only on the people but also on the towns, cities, and economic infrastructure, such as irrigation works systems (e.g., Giesecke and Silgado 1981). However, because of the unusual shallow-angle subduction under northern and central Peru, active volcanism does not occur here as it does in Ecuador and in southern Peru, Bolivia, northern Chile, and Argentina (Barazangi and Isacks 1976). Consequently, this sector of the central Andes lacks catastrophic volcanic eruptions.

El Niño Southern Oscillation (ENSO) dominates present-day climatic variability on inter-annual timescales in the tropics and involves both the atmosphere and the ocean in the tropical Pacific (e.g., Maasch 2008). On the central Andean coast, El Niño warms near-shore waters, bringing torrential rainfall to the land and depressed biotic productivity to the adjacent ocean. Frequency, intensity, and duration of El Niño events generally follow a latitudinal gradient, decreasing toward the south. However, each event is different, and rainfall can skip valleys or occur in different sectors of valleys, with variable consequences. In this largely unvegetated region, the rains often lead to destructive flooding as well as plagues of insects and diseases. Earthquakes produce abundant debris on the landscape; El Niño flooding mobilizes this unconsolidated sediment, often resulting in coastal progradation (seaward expansion of the shoreline) and inland dune incursions (see Sandweiss et al. 2009 and discussion later in this chapter).

## CHALLENGES

To understand how short-, medium-, and long-term geological, climatological, and environmental processes are interrelated with one another and with human activities, we must take into account epistemological foundations and fundamental principles of scientific methodology. The epistemological issues concern the dimensions by which we measure phenomena under scrutiny, while the methodological concerns focus on relating phenomena and events to one another.

In attempting to insert rigor into archaeological investigations, many years ago Albert C. Spaulding (1960) underscored the importance of distinguishing among three different analytical dimensions: space, time, and form. By definition, a dimension is a phenomenon that requires its own measuring device, and such is the case for these three. The distance from, say, Cambridge, Massachusetts, to Orono, Maine, is a constant (so long as it is "as the crow flies" or along the same route) and is measured in kilometers, miles, or some other standardized units. The time it takes to get from one city to the other, however, varies depending on mode of travel and many other factors and is measured by time units that may be expressed as minutes, hours, days, or even weeks (depending on the traffic). One measurement system cannot be converted into the other, and neither the distance between the cities nor the time it takes to travel to them can be converted into "form." Time itself is a form of measurement. It marks change and duration. As in the cases of space and time, form has its own intelligibility. It comprises not only the shape of things but also their qualities, such as color and texture (see Wagensberg 2008).

Investigators, whether archaeologists, Shakespearean scholars, or crime detectives, commonly use secure information in one dimension to infer information in one or more others. "Secure information" is often derived from generalized principles or laws. For example, the geological law of superposition (that, without later modification, lower strata are older than upper strata) is used to infer that differences between the fossils or artifacts distinctive to particular strata or ranges of strata represent change through time. Form—the distinctive fossils or artifacts—and (the products of) time—the inferred change—are thus accounted for in such exercises.

Fairly commonly, secure information in two dimensions aids in learning something in the third dimension. For example, the consistent identification of artifacts with distinctive attributes, such as decoration or mode of manufacture (formal dimension), within a restricted geographical region (spatial dimension) may help to identify or at least narrow the range of possibilities for the time period of their use or popularity in a new region of investigation when the time of use is known elsewhere. These simple rules for relating data from different dimensions have wide use and are essential for many different kinds of studies.

As we are concerned with changing human-environmental relations over time, issues of relations between the formal and temporal dimensions are particularly relevant to our interests. We chronicle forms that endure or change through time, and we are interested in the relationships of different forms to one another through time, such as different settlement types in relation to environmental changes.

This leads us to issues of collation, correlation, and causation (Sandweiss and Quilter 2008), which are steps in a chain of increasingly significant activities leading to plausible explanations for past events. They are mutually and sequentially dependent on one another so that without collation, the other two steps cannot be carried out and without correlation, causation cannot be reasonably posited.

Collation is the demonstration that events occurred simultaneously. We collate manuscript papers by placing them together in the same pile or group, and we collate events by showing that they occurred at the same time. This first and apparently simple step is extremely difficult to achieve in archaeology, however, especially for short-term events. As with most things in archaeology, when the temporal scales of events are of long duration, we can be fairly confident in collating them. For example, we can collate a gradual decrease in rainfall with changing environments and settlement patterns by showing that these events occurred at the same time. So long as anthropological archaeology saw change as slow, within evolutionary or neo-evolutionary theoretical frameworks, the focus was on looking at the "big picture" and concomitant big events. With an awareness of the potential for short-term events to have long-term consequences, such as in punctuated equilibrium, we are faced with the difficulty of trying to collate events when chronological measuring devices in archaeology are generally coarse, with resolutions at a century or half-century scale at best. Except in rare and special cases, for now and perhaps the foreseeable future there is no solution to this problem except to wait for more precise temporal measuring tools that will allow for tighter collations of events of interest to be made.

There are cases in which we can make tighter collations, however. For instance, if we excavate a shell heap and find a mollusk shell that incorporates growth or geochemical anomalies known to be caused by El Niño, we can infer that the associated stratum was deposited very close in time to the event (although various exceptions can be raised). More broadly, we can look at environmental history encoded in a shell across its lifespan and know something about conditions and changes in conditions for that span and thus for associated archaeological events. Over time, the development of collations of these kinds can lead to fairly robust data sets that can be inferred to have value in developing correlations.

Correlation, in formal terms, refers to demonstrating that events of interest covary in a statistically significant way. Correlation therefore requires even more rigor than does collation in linking events occurring through time. To continue with the case previously mentioned, the observation that, for a particular region, there was a change in rainfall in the past and that at the same time there was a changing environment and that, further, human settlement patterns appear to have changed while these other events were taking place must be more strongly associated to proceed further, to causation. In archaeology it is often difficult if not impossible to show covariance in a statistically significant way. This is again a result of the high values for standard deviations in our attempts to gain confidence that events are occurring at the same time and because it is hard to know what to quantify, how to quantify it, and how to establish an acceptable degree of uncertainty in what we might consider significant covariance.

A significant challenge in archaeology is the fact that our sample size is commonly very small and the population from which it is drawn is usually, at best, highly uncertain while the universe from which it was taken is invariably unknown. There is commonly high variability in the distribution of archaeological materials throughout a site, even if the site itself is fairly well delimited. The quantity and distribution of shells or human burials in middens may vary considerably from one place to another within the entire distribution of middens. Although archaeologists commonly employ stratified and other forms of random sampling of deposits, we cannot always rely on these methods to provide information about the overall quantity and nature of the materials that could be sampled.

As might be expected, causation is the most difficult level of all of these linked investigative procedures. Events as rapid, obvious, and well reported as the eruption of Vesuvius can clearly document, following our example, that a settlement pattern changed as a result of environmental factors. "Quality" here is important: a well-known case of a volcanic eruption that sent waves of ashes (whether at Pompeii or Ceren [Sheets 2006]) leaves little doubt as to the cause of what we might banally refer to as a "change in settlement."

In the case noted earlier—the changing rainfall-environment-settlement pattern chain that could be collated and might be correlated—it becomes much more difficult to move to the next level of causation, simply because human beings are complex and their reasons for doing things may or may not be a result of other events that are seen to collate or correlate. What appear to be clear-cut cases of intense causal agents, such as volcanoes, do not always provide sufficient evidence for causality. Volcanic eruptions have the advantage (for archaeologists at least) that most societies lack the capacity to clean up after them, but both hurricanes and earthquakes are short-term, strong causal agents that may leave few archaeological traces after sufficient time has passed and recovery has occurred (see, for instance, Wilkerson 2008). The degree to which societies are vulnerable even to volcanoes, however, is highly variable, as is the rate of recovery (Sheets 2008). The same must therefore hold true for other disasters, with the precise nature of the catastrophe, the rate at which it occurs, and the various components of the society experiencing the catastrophic process all playing important roles in how events play out in human terms.

## SCALES

Consideration of intense causal agents leads us to ponder the scales of impacts, societies, and responses. Scales cannot be seen as isolates, however, because size alone is insufficient to understand processes occurring through time. Just as a single drop of water on a boulder will have little effect but many drops of water over a long time will bore a hole through granite, so, too, small events over long periods of time can have grand consequences. Again, when archaeology is encumbered by coarse resolution in its view of phenomena in the three dimensions of space, time, and form, it is forced to look mostly at large-scale impacts occurring on grand societal levels and to see responses on similar scales.

The chronologies archaeologists commonly create are cultural-historical periods. They consequently represent major ruptures in human societies and, frequently, drastic environmental change as well. This creates its own problems in that many different events are seen as collated and correlated, but causation, especially simple, straightforward, mono-causal varieties, becomes elusive. Whether it be the Roman Empire or the Classic Maya, the breakdown of what appear to have been relatively stable (though, in reality, constantly changing) systems seems to occur in many different sectors of the natural and cultural worlds simultaneously. Even if causation could theoretically be narrowed to a few key components of the system, doing so becomes extremely difficult for archaeologists, who should take some comfort in the fact that it seems equally elusive for historians who often claim superior data sets for understanding the past.

The relation of the complexity of a system to its ability to withstand changes in its environment is, fittingly, a complex issue. *Complexity* is a loaded term, especially when applied to human cultures or social systems, and, as noted earlier, simplistic notions of sociocultural evolution no longer seem valid as approaches to understanding the long-term human story. The classic case of the Western Desert Aborigines can be cited. Their technology might be termed "stone age" by a previous generation of anthropologists, but it is actually highly efficient and technologically sophisticated—as in the case of compound tools that, in Swiss Army knife fashion, provide multiple working edges and surfaces in a single, light, portable instrument (Gould 1970). Furthermore, while Aboriginal technology *might* be considered simple, Western Desert kinship systems are among the world's most complex. Because it was important to them, Western Desert Aborigines easily kept track of marriage rules and clan affiliations that can boggle the mind of an outsider. Finally, both the technology and the social system of the Western Desert Aborigines were potentially the products of the same number of centuries as Western European or East Asian systems, so they cannot be assumed to be some kind of relicts from the past.

At the same time we can recognize that ethnographically known, apparently simple societies are not so simple and that they are not fossils of a distant past, we are faced with the demonstrated fact that, in broad view, human life on the planet has gone through dramatic changes since the Lower Paleolithic, as Timothy Kohler states so elegantly in his chapter in this volume. Long ago, V. Gordon Childe (1925) emphasized the Neolithic, Urban, and Industrial Revolutions; since then, other scholars have noted additional dramatic changes, such as the Broad Spectrum Revolution (Flannery 1969), among others. However many revolutions one wishes to cite, the underlying fact of the matter is that 30,000 or 40,000 years ago, all humans were hunter-gatherers. Through time, the number of hunter-gatherers has diminished while the number of agriculturalists has grown, and, increasingly, more people are living in urban centers and are not directly involved with food production. These changes have been accompanied by a great number of others, such as increased dependence on fossil fuels and the machinery that runs on them and, more recently, on computer technology. All of these changes and more have occurred on an increasingly global scale, so even people who do not have many machines or computers are affected by them.

These global changes can be referred to as increasing "complexity" in the sense that Emile Durkheim (1984 [1893]) proposed that societies consist of increasingly specialized subunits that interrelate in complex ways. Recently, Ian Hodder (2006) has referred to the increasing "entanglements" people have with material culture, including such things as infrastructure, on which people become dependent and which consequently traps them in systems of dependency. For Peru, this trend is clear in the change from early gathering-fishing-hunting communities that had low investments in complex infrastructure and so could adapt to changing circumstances, such as the dramatic changes in resource availability and locations during El Niño events and the increasing complexity and entanglements that occurred with the growth in dependence on irrigation agriculture, urban settlements, and the associated socio-political and economic systems that were tied to them.

**5.3.** *The Ascope Canal in the Chicama Valley is reputed to have been built by the Chimu (ca. AD 1100–1450), though irrigation systems are notoriously difficult to date. Photo by Jeffrey Quilter.*

The advantages of mobility and flexibility in the face of changing circumstances that existed in Peru and everywhere else during early prehistory also had negative aspects. One price of irrigation agriculture was a reduction in the number of buffering mechanisms that could overcome short-term shortages and other recurring negative events that could not be solved by moving to a different place or exploiting a different resource. Through time, the challenges of the "known unknowns" of preparing for the next famine were met by narrowing the range of subsistence strategies to grains and other foods that could be stored for relatively long terms and by building infrastructure—irrigation canals (figure 5.3) and storage facilities—that would both maximize the amount of resources ("quantity is its own kind of quality") and provide buffering systems, through storage, to get through the bad times.

Once Peruvian coastal economies became dependent on irrigation agriculture as the primary means of subsistence, issues of resilience, vulnerability, and hazards arose similar to those of the Hohokam, as discussed by Margaret Nelson and her colleagues in this volume. A future comparison of the two situations might be enlightening, especially because while many of the advantages and disadvantages of irrigation agriculture were similar in both societies, there was also a fundamental difference. In the case of coastal Peru, the huge protein larder of the Humboldt fisheries provided a distinct advantage in surviving times when agriculture failed. A further complication is that maritime resources primarily provided protein while agriculture mostly offered carbohydrates in the form of maize and tubers, though the importance of beans, fruits, and other foods is not to be taken lightly.

Whether foragers, fisherfolk, or agriculturalists, it is the "unknown unknowns" that create the most problems when those unknowns provide challenges to prosperity or survival that cannot be met successfully or, sometimes, at all. Commonly, short- or medium-term successful adaptations have within them the seeds of their own downfall. Common examples include directly overexploiting a resource or creating a situation that indirectly results in the unsustainability of what was thought to be a stable adaptive system. The latter includes such activities as short- or medium-term behaviors that have long-term consequences.

While many generalizations can be made regarding general patterns of human-environmental relations, as well as the theories and methodologies by which we may try to understand past events, much depends on the particular circumstances of a given region and the people who inhabit it. Science depends as much on induction as on deduction, and thus we will turn to the specific conditions of coastal Peru to explore many of the issues presented earlier from both a particularist and a general perspective.

## CONTRIBUTIONS

### Key Hazards

We do our research in an extreme environment—the central and north coast of Peru. Because the area is lapped by the Pacific Ocean and lies well within the tropics (between about 3°30' and 18°20' S latitude), those unfamiliar with the region might imagine balmy waters and waving palms. The truth is far different, however. The coastline shared by northern Chile and Peru (see figure 5.1) is one of the world's driest deserts (no palm trees without irrigation) thanks to the rain shadow effect of the Andes Mountains rising abruptly to the east and the cool Humboldt or Peru Current that sweeps up the western side of South America from the Antarctic (no balmy waters) (Lettau and Lettau 1978).

Despite the general lack of precipitation, however, humans have inhabited the Peruvian and Chilean coast for at least 13,000 years (Sandweiss 2008; Sandweiss et al. 1998). Over time, populations grew, socio-political complexity emerged, and eventually large-scale empires arose. The economic basis for these developments rested on two key environmental factors: the high productivity of the marine environment resulting from intense nutrient upwelling in the Peru Current, and the potential for irrigation agriculture using water from streams arising in the adjacent Andes and flowing west to the coast (Moseley 1992, 2001).

Extreme aridity is not the only disaster that plagues the South American coast. The Andes Mountains exist for a reason: the oceanic Nazca Plate is subducting under the South American continental plate along the western margin of Peru and Chile, pushing up the Andes and causing frequent earthquakes (see Lamb 2006). On August 15, 2007, for instance, a magnitude 8.0 earthquake struck near Ica on the coast south of Peru, killing hundreds of people and destroying tens of thousands of buildings (Quakes 2007). Many sectors of the Andes also suffer volcanic eruptions, although the north-central part of Peru on which we focus does not experience this disaster; here, the Nazca Plate is subducting at a shallower angle than elsewhere, so it does not go deep enough to melt and produce magma (Barazangi and Isacks 1976).

"Normal" conditions, consisting of a cool ocean and arid land, are interrupted at irregular intervals by El Niño, the eastern Pacific expression of the inter-annual climatic perturbation known as El Niño Southern Oscillation (NOAA n.d.). El Niño warms the coastal waters from Ecuador south into Chile. This has consequences on land and sea. In the ocean, deepening of the thermocline (the boundary between warmer, mixed surface water and deep, cooler water) suppresses nutrient upwelling. From plankton up the food chain to small and large fish, birds, and sea mammals, major El Niño events result in tremendous loss of biomass through mortality and out-migration (e.g., Barber and Chávez 1983). Some northern, warm-adapted species migrate south along the coast and replace the local biota that has died or headed even further south, but total available biomass is significantly reduced.

On land, the warmer sea surface temperatures lead to convective storms. Rain in a desert disrupts the "normal" system when people have adapted to aridity. With a tectonically destabilized hydrological system, abundant earthquake-produced debris, and little vegetation to hold surface sediment in place, El Niño rains cause destructive erosion. In today's regime, floods blow out roads, bridges, and buildings (see, for instance, photos from the 1982–1983 El Niño in Canby [1984]). People drown. Standing water creates breeding grounds for insects that carry diseases such as malaria and dengue fever, and plagues of locusts and rodents consume crops not destroyed by the floods. The early colonial inhabitants of the northern coastal region faced these same hazards, as dramatically described by local witnesses following the first major El Niño event of the Colonial period, in 1578 (Copson and Sandweiss 1999; Huertas 2001; Quilter 2011). One, a Spanish priest in the Lambayeque Valley, described the attempts at farming after the rains:

> After the canals were fixed, the Indians hurried to plant and there came the plagues . . . such that any seed that grew a hand's width above the ground

> was eaten by crickets and locusts and some green worms and yellow ones and other black ones that were bred from the putrefaction of the earth because of the said rains . . . [After several plantings], when the fruit was ready to harvest there was such a multitude of mice that this witness didn't believe the Indians and went to some fields and saw mounds of mice like piles of sand . . . the mice were the size of medium rabbits . . . This witness counted a mound of them and there were 500 more or less. (Francisco de Alcocer 2001 [1580]: 42 [f. 220v./221r.]; authors' translation)

The hazards associated with El Niño are bad enough, but the risks to humans on the Peruvian coast are even worse because of synergistic interactions, what Michael Moseley has called convergent catastrophes (e.g., Moseley 1999; Satterlee et al. 2001). Following earlier work on coastal processes and prehistory (Moseley and Richardson 1992; Moseley, Wagner, and Richardson 1992; Sandweiss 1986), Moseley and his colleagues have identified a devastating suite of sequential disasters for the Peruvian coast (Sandweiss et al. 2009).

Earthquakes destabilize the drainage system and produce loose debris on the largely barren desert surface. El Niño–driven floods then erode the surface, moving the debris into the rivers and out to the shoreline. In addition to destruction by flooding of planting surfaces and infrastructure such as houses and canals, El Niño brings diseases and crop plagues while depressing productivity in the marine environment.

The sediment that reaches the coast forms large, temporary deltas at river mouths and then gets strung out along the shore to the north as beach ridges. This reduces the extent and productivity of intertidal zones. Sand from the beach ridges blows inland on the constant onshore breezes (see figure 5.2), eventually covering field systems and reducing agricultural productivity.

## Past Impacts

Working with Peruvian archaeologist Ruth Shady—who has been excavating large Late Preceramic sites such as Caral (figure 5.4) in the Supe Valley (e.g., Shady Solis 2005; Shady Solis, Haas, and Creamer 2001), 200 km north of Lima—Moseley, Sandweiss, and colleagues were able to track the coastal disaster sequence beginning about 3,800 years ago (Sandweiss et al. 2009). Several sites had clear evidence of earthquake damage followed by reconstruction. A massive beach ridge formed along the shore and eventually blanketed about 100 km of coastline. Bays filled with sediment, and sand began blowing inland. In several sites, sand deposits were covered by a final construction level, less well made than earlier structures, and then the sites were abandoned.

In the Supe case, collation is clear, frozen in time by human construction. Given the tight chronology, there is almost certainly correlation between the disasters and the human activities culminating in abandonment. Whether the

**5.4.** *Two of the six major mounds at the Late Preceramic site of Caral in the Supe Valley, Peru, the largest Late Preceramic site on the Peruvian coast. Photo by Daniel H. Sandweiss.*

disasters were causative remains an intractable question, though it is tempting to assign them some role in the regional cultural changes at the end of the Late Preceramic Period. It may help to look at this case from a broader spatial and temporal perspective. First, "abandonment" refers strictly to the monumental sites; we do not know what happened to the population of the Supe and adjacent valleys after the large sites fell out of use. This is an urgent topic for future research. Second, monumental, preceramic, or aceramic sites continued for several hundred years on the peripheries of the Supe Culture area, to the north at Salinas de Chao (Alva 1986) and to the south at El Paraíso (Quilter 1985), beyond the reach of the massive beach ridge that fed the invading sand sheets. Were these sites homes to different societies with different cultural dynamics? Were they successful for longer simply because they were safe from the sand and other disasters? Did they receive migrants fleeing the Supe area who enhanced their labor pools and contributed to their longer survival as monumental sites?

Regardless of whether synergistic disasters caused the cessation of monument building by the Supe Culture, earthquakes, El Niño, and related coastal processes continue to operate in the region today. Because these processes interact at an intermediate timescale, over the course of decades, modern planners are unlikely to take them into account. These are the kinds of lessons for today that archaeology can draw from the past because of its privileged view of human-environment interaction at intermediate (decadal) to long (centennial to millennial) timescales.

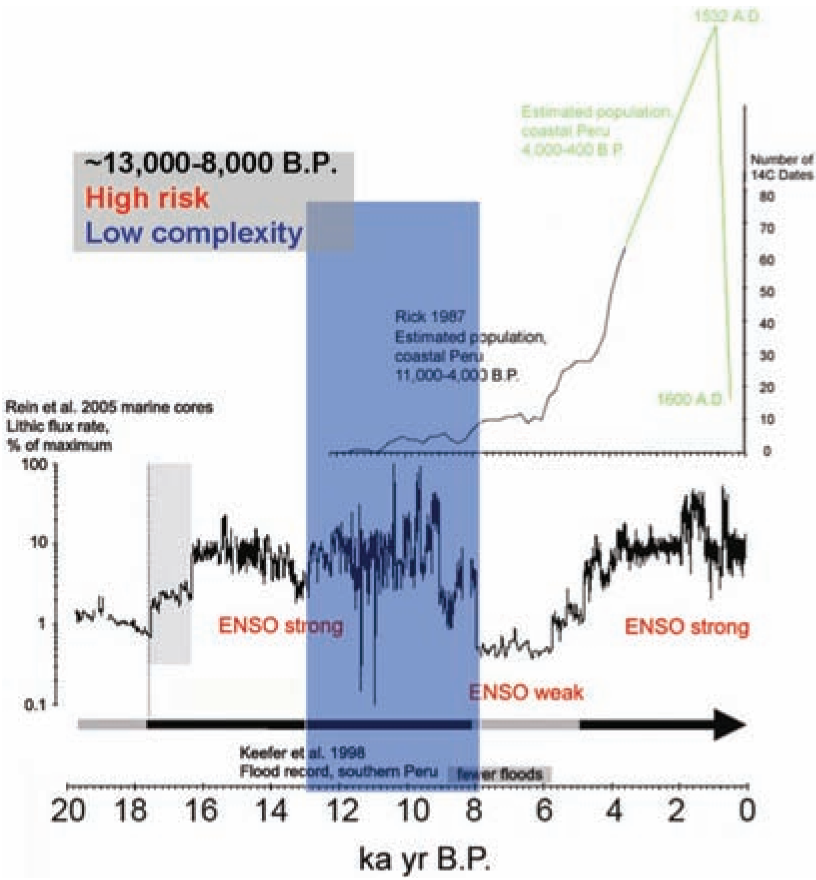
Turning to a longer timescale, we see an intriguing pattern in the relation among demography, complexity, and risk from disasters on the Peruvian coast. Through time, population grew, though it is notoriously difficult to quantify prehistoric population levels. To substantiate our assertion of the direction and approximate rates of growth, we spliced and smoothed John Rick's (1987) radiocarbon date–based curve for the Preceramic Period (ca. 13,000–3600 calendar years before present) with David Wilson's (1988) site survey–based curve for the coastal Santa Valley (~9°S) for the Initial Period through the Middle Horizon (ca. 3,600 to 1,000 years ago, or 1600 BC to AD 1000).

For the final two prehistoric periods, the Late Intermediate Period time of the north coast Chimu Empire and the Late Horizon or Inca Empire (ca. AD 1000–1532), Wilson's curve shows a population decline in the Santa Valley; however, he recognizes that continuity in the local ceramic tradition may mask the continued occupation of sites under Chimu and Inca domination. Considering ethno-historic records relating to population at the time of the Spanish Conquest in AD 1532 (e.g., Cook 1981) and broader archaeological patterns (e.g., Moseley 2001), our figures (5.5–5.8) show continued population growth through these final two prehistoric periods. The early historical record is very clear on the demographic disaster that followed the Spanish Conquest, with depopulation ratios of as much as 100:1 in less than a century for some coastal valleys (Cook 1981).

The archaeological record shows a general increase in social complexity through time along the coast (e.g., Moseley 2001; Richardson 1994). The earliest settlers were mobile or semi-sedentary hunter-fisher-gatherers (Sandweiss in press) who became sedentary shortly before 5,000 years ago, when they began to build large monuments. Despite fluctuation in monument building, such as the Supe case outlined earlier, the volume of construction and the nature of social and economic organization evidenced in the archaeological record and (for the latest period) in the ethno-historic record show a general trend toward larger volumes and more complex arrangements.

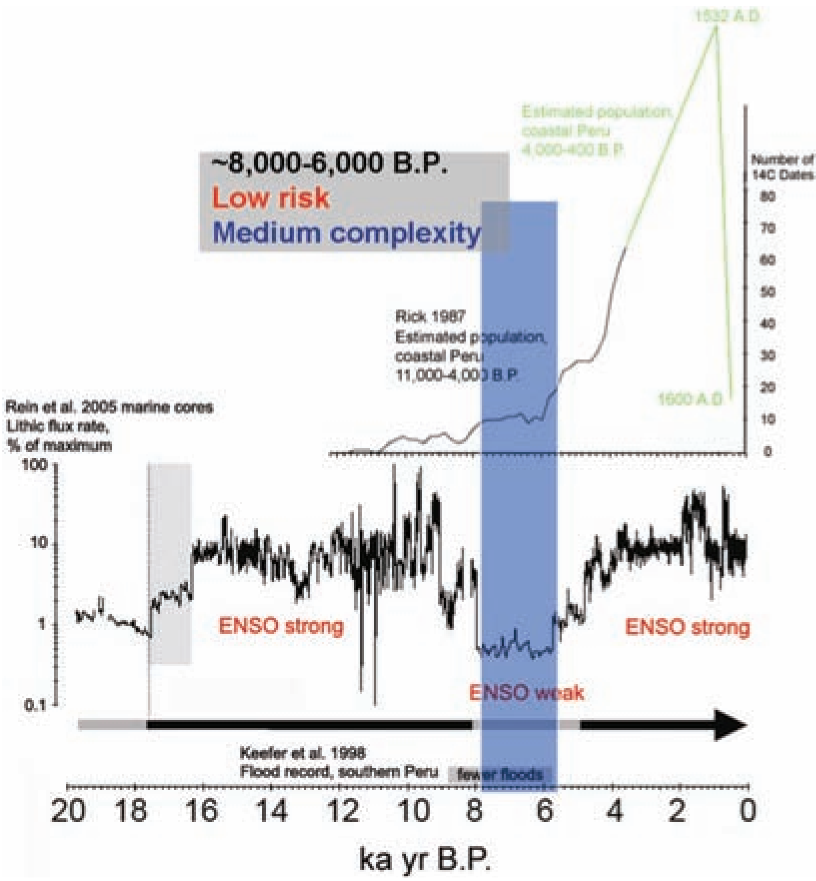
The frequency of volcanism and tectonically driven earthquake and tsunami activity should not have fluctuated through the time of human occupation; these events do not have a regular recurrence interval but do recur at average rates through time that are independent of climate on a human timescale. In contrast, El Niño frequency did change throughout the period of human occupation of Peru (Keefer et al. 1998; Rein et al. 2005; Sandweiss et al. 2007), and we therefore use El Niño as our proxy for risk (figures 5.5–5.8).

- From ca. 13,000 to 8,000 years ago, El Niño occurred at an unknown frequency; we assess risk as high, but complexity and population were low (figure 5.5).




**5.5.** *Population, risk, and complexity on the Peruvian coast, 13,000–8000 BP (years before present/AD 1950). Population curve drawn from Cook (1981), Moseley (2001), Rick (1987), and Wilson (1988) (see text). Risk is based on frequency/intensity of El Niño, from Rein et al. (2005) and Sandweiss et al. (2007). Complexity is based on the authors' experience and the general literature (e.g., Moseley 2001; Richardson 1994). Figure drafted by Kurt Rademaker.*

- From ca. 8000 to 6000 cal BP, few or no El Niño events took place, coastal waters were seasonally warmer than present in northern Peru, and there was probably seasonal rainfall north of 10°S. At this time, population began to grow but remained low overall. Complexity increased as the first sedentary villages were founded. Risk was minimal (figure 5.6).
- From ca. 6,000 to 3,000 years ago, El Niño events were strong but infrequent; coastal waters were cool along all of Peru. Complexity increased with the onset of large-scale monument building, evidence of different

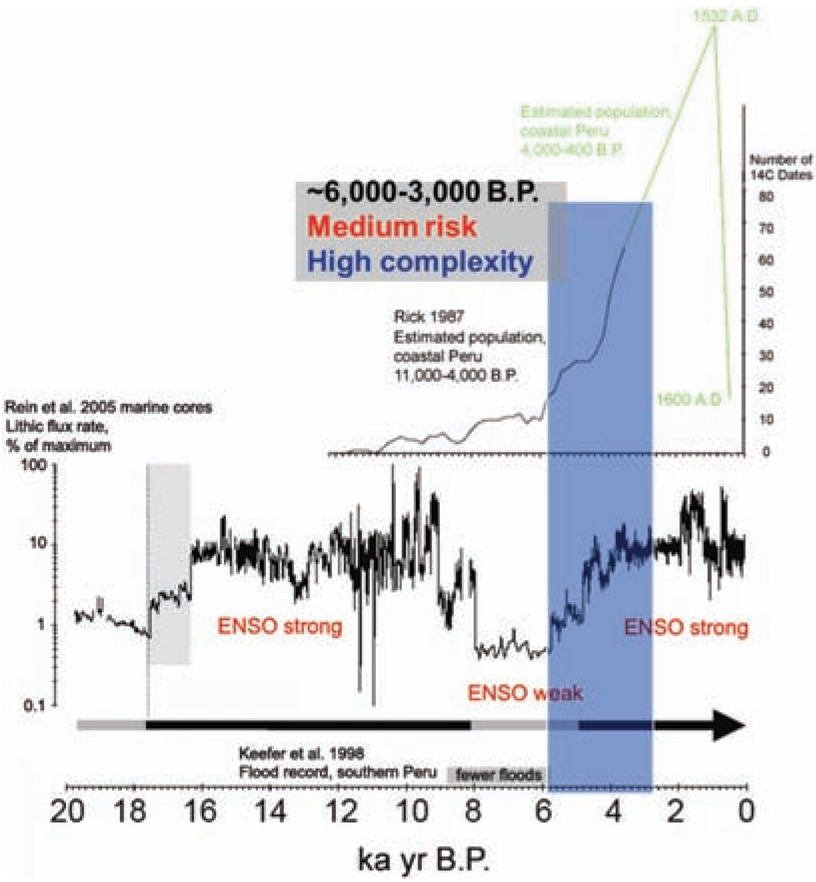



**5.6.** *Population, risk, and complexity on the Peruvian coast, 8000–6000 BP. See figure 5.5 caption for sources. Figure drafted by Kurt Rademaker.*

social classes at monumental centers, and a diversifying economy. The rate of population growth increased notably (figure 5.7).

- From ca. 3000 cal BP to present, El Niño variability fluctuated within the range of modern variability. Population grew rapidly until the Spanish Conquest in the early 1530s and then plunged precipitously. Complexity also increased, from state-level societies to large (ultimately pan-Andean) empires (figure 5.8).

Though very broadly painted, this record shows that through the prehistoric era on the coast of Peru, increasing population and growing complexity were accompanied by ever greater risk from natural hazards. In stark contrast, the demographic collapse after the 1530s was *not* caused by natural disasters but instead resulted from human-induced disasters—warfare, economic and

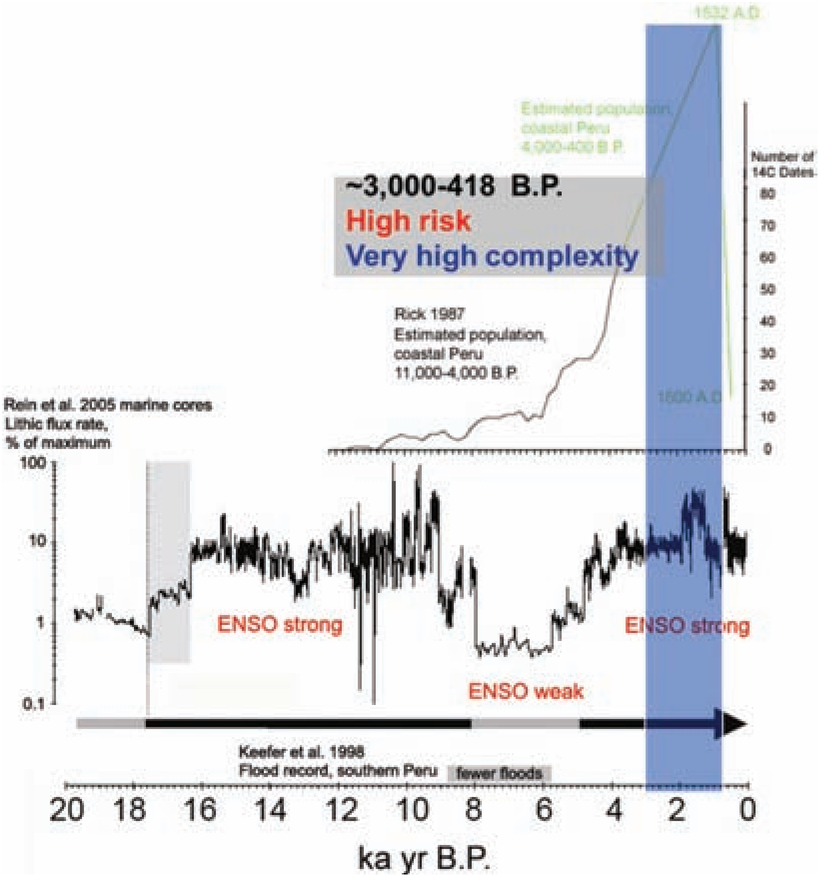



5.7. *Population, risk, and complexity on the Peruvian coast, 6000–3000 BP. See figure 5.5 caption for sources. Figure drafted by Kurt Rademaker.*

social disruption, and disease (Cook 1981; cf. Kiracofe and Marr 2009). This pattern seems counterintuitive at first glance but may hold important lessons.

## CONCLUSION

As noted earlier, the coarse resolution of archaeological views of the past results in many issues remaining unclear. The turbulent times of change between recognizable cultural periods are difficult to interpret. Even if fine-grained resolution were available, some issues would be elusive. For example, demographic collapse as a result of diseases that leave no easily recognizable signatures on human remains (especially in regions where only bones remain) would be hard




5.8. *Population, risk, and complexity on the Peruvian coast, 3000 BP–present. See figure 5.5 caption for sources. Figure drafted by Kurt Rademaker.*

to determine directly. Population drops marked by reduced village sizes may be difficult to recognize when archaeologists cannot be sure if particular houses were abandoned or, if abandonment is noted, of the reasons for a smaller population when many reasons are possible. These negative aspects of archaeological research must be balanced, however, with the discipline's great potential to examine long-term changes.

The clear pattern of increasing population sizes on the Peruvian coast, apparently throughout prehistory and certainly in its later phases, is a testament to humanity's success as a species in adapting to a challenging and changing environment. Embedded in this grand narrative are interesting questions about the shorter-term patterns of the rise and fall of what are generally termed "complex" societies. From a shorter-term perspective, complexity is never totally lost, but the geographic extent of complex systems and the proportion of the overall population incorporated at any given moment in a single system oscillated through time. Complexity, however conceived, came early to Peru, but there was a clear pattern of development followed by disintegration of complex systems over periods that appear to have lasted for more than a few generations. While these are among the most difficult archaeological periods to examine, they offer the potential of telling the most interesting stories, both in and of themselves and as means by which to understand how societies respond to stresses and reorganize themselves in their wake.

As a final note, if the growth in population in Peru is marked as a general success story, it seems clear that this is part of a general trend throughout the world. We are all too cognizant of the fact, however, that the general upward trend in growth of human populations is also tied to the increasing interconnectivity of events in one place in the globe with those in another. Indeed, the demographic collapse brought by the Spanish invasion was correlated with the introduction of new plant and animal species in both the Old World and the New. This process was the creation of the Modern World. As human populations are growing, they are not only becoming more interrelated but are also affecting the natural environment more radically. It remains to be seen whether the global natural-cultural system can be sustained for the long-term health of human inhabitants without undergoing drastic alterations that will be viewed as catastrophes by those who experience the sharpest changes.

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## UNDERSTANDING HAZARDS, MITIGATING IMPACTS, AVOIDING DISASTERS

### Statement for Policy Makers and the Disaster Management Community

Peru is famous for the soaring, seemingly ageless Andes Mountains and a coastal desert that preserves archaeological remains as if they had been abandoned decades instead of centuries ago. These impressions of long-term stability are illusions, however. Instead, the Andes and the coastal desert are the results of highly dynamic processes.

The jagged Andes are young mountains still in the process of forming as the Nazca Plate, under the ocean, pushes below the continent and shoves the mountains upward. The desert is a product of the cold, offshore Humboldt Current that prevents rain from falling on the coast. The pressure of the Nazca Plate results in a steady uplifting of the desert coast, while the pressures of the geological plates create volcanoes, earthquakes, and tsunamis. The slow uplift of the coast disrupts irrigation systems and other infrastructure in time periods that are best noted over the span of centuries and are thus imperceptible in a single human lifetime. Changes in the Humboldt Current and the release of pressure on the tectonic plates, however, occur suddenly and unexpectedly.

The overriding of the cold waters of the Humboldt by warm waters from the north is referred to as El Niño Southern Oscillation events, or "El Niño" events in the popular press. Once barely known, El Niños are now understood as related to distinct weather patterns throughout a huge area of the globe. Nevertheless, scientific understanding of how El Niños are patterned is still under investigation. The only way to fully investigate this issue and related events is through archaeology and allied sciences because they provide views of (pre)history in remote times.

There are challenges to archaeological investigations of past human-environment interaction, but they do not hinder them. In our chapter we present a long-term view of hazards and the human response for the desert coast of Peru and then focus on a specific example of synergistic hazards. At the broader scale, we collate El Niño events and major cultural and population changes from 13,000 BP to the present. Through time, increasing population sizes and growing complexity correlate with greater risks from natural hazards, with implications for human resilience—as life became riskier, populations increased and so did social complexity until a human hazard, the Spanish Conquest, brought local societies to their knees and decimated their populations.

Looking specifically at the end of the first period of monumental society, we see synergistic hazards operating in ways that must still occur today. The chain of events starts with earthquakes producing debris. El Niño rains wash this debris to the coast, coastal processes expose the sand portion of the debris to the wind, and the sand turns agricultural fields into deserts. These processes are ongoing but at a timescale too great to be easily recognized except by extensive study.

Current research is starting to examine the details of human ecodynamics in these periods to see how specific societies responded to changing events and how we can learn of them for our own future.