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LOS DILUVIOS DE 1578 AD: HOW SPATIAL APPROACHES TO THE DOCUMENTARY RECORD CAN CONTRIBUTE TO THE ARCHAEOLOGY OF EL NIÑO

LOS DILUVIOS DE 1578 AD: CÓMO LOS ENFOQUES ESPACIALES A LOS FUENTES DOCUMENTALES PUEDEN APORTAR A LA ARQUEOLOGÍA DE EL NIÑO

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Abstract

With its long-term perspective, archaeology can tell us much about cultural responses, material adaptations, and the development of intergenerational knowledge about El Niño. However, we are limited by what we cannot see: actions that are ephemeral or non-material and leave no recognizable trace—or no trace yet recognized. We review spatial approaches to historical documents that can complement archaeological study to yield insights into socio-cultural responses to El Niño. We tested spatial-historical and spatial modeling techniques on witness testimonies of an El Niño that devastated Peru's North Coast in 1578 AD. We extracted details from a subset of testimonies into a relational database paired with a geographic information system, allowing us to explore the geography of the disaster and community responses. Some of our results echo archaeological observations of responses to El Niño. Such cases have the

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potential to enhance our understanding of how these responses were developed, sustained, and deployed. Although based on a small number of testimonies, our results demonstrate how historical data can be integrated with archaeological research to provide a more complete understanding of past community responses to El Niño that may improve how present-day populations prepare for future events.

Keywords: Spatial Analysis, El Niño, least cost path, geographic information system, spatial history.

Resumen

Con su perspectiva de largo plazo, la arqueología puede aportar significativamente sobre las respuestas culturales, las adaptaciones materiales y el desarrollo del conocimiento intergeneracional sobre El Niño. Sin embargo, estamos limitados por lo que no podemos ver acciones que son efímeras o inmateriales y no dejan evidencia reconocida. En este artículo revisamos los enfoques espaciales de los documentos históricos que pueden complementar el estudio arqueológico para obtener información sobre las respuestas socioculturales a El Niño. Probamos técnicas de modelado espacial-histórico y espacial en testimonios de testigos de un El Niño que devastó la costa norte del Perú en 1578 dC. Extrajimos detalles de un subconjunto de testimonios a base de datos relacionales emparejada con un sistema de información geográfica, lo que nos permitió explorar la geografía del desastre y las respuestas de la comunidad. Algunos de nuestros resultados reflejan las observaciones arqueológicas de las respuestas a El Niño. Estos casos tienen el potencial de mejorar nuestra comprensión de cómo se desarrollaron, mantuvieron y desplegaron esas respuestas. Aunque se basan en un pequeño número de testimonios, nuestros resultados demuestran como los datos históricos pueden integrarse a la investigación arqueológica para proporcionar una comprensión más completa de las respuestas pasadas de las comunidades frente a El Niño que pueden mejorar la forma en que las poblaciones actuales se preparan para eventos futuros de la misma naturaleza.

Palabras Clave: Análisis espacial, El Niño, senda de menor costo, sistema de información geográfica, historia espacial.

In 1578 AD, an El Niño event ravaged several recently centralized Indigenous communities, called reducciones, on the North Coast of Peru. Two years later, royal authorities in Lima dispatched royal scribe Francisco de Alcocer to investigate these events in response to a series of petitions for temporary tribute relief put forth by Indigenous leaders in the affected region (Alcocer 1987 [1580]). About half of the original transcripts were recovered and published by Peruvian ethnohistorian Lorenzo Huertas Vallejos (1987, 2001).

Previous studies (e.g. Copson and Sandweiss 1999; Sandweiss and Maasch 2020) have reviewed some of the coping strategies, mitigations, and other adaptations and responses to El Niño observed in this document and archaeologically. Although we are both archaeologists by training, we were inspired by our additional interests in spatial history (Rodgers) and geospatial modeling (Landazuri) and intrigued by what spatial approaches might offer the analysis of the Alcocer testimonies and, more broadly, the archaeology of El Niño. Although history and archaeology both investigate the past, differences in temporal scale and specificity can make it difficult to bring historical and archaeological evidence together in productive ways, especially in the investigation of long patterns of human-environment interactions and adaptation. However, both archaeology and history are situated in place, and spatial approaches may improve their complementarity in addressing questions related to long-term human interactions with and resilience to El Niño.

As others have noted before us, (e.g., Copson ca. 1990s; Sandweiss and Maasch 2020), testimonies of the 1578 AD El Niño provide an opportunity to reconstruct adaptations not visible in the archaeological record, for example, responses that do not leave physical traces or where such traces are unlikely to survive. The testimonies also provide an opportunity to connect archaeological patterns with described experiences and behaviors. Finally, where some of the people present for the 1578 AD event were also alive prior to Spanish colonization, the testimonies offer the ability to reconstruct how ancestral adaptations and knowledge were preserved through this tumultuous period (Sandweiss and Maasch 2020).

We decided to test these opportunities by applying spatial historical and spatial analytical techniques to a subset of testimonies from the Lambayeque Valley. We developed a relational database with a geospatial component to extract and store details from the testimonies related to witnesses' experiences of the El Niño of 1578 AD and the strategies Indigenous Lambayecanos employed to endure its aftermath. Our work with the database allowed us to confirm and expand on responses identified through previous research. We also used details from the database to inform geospatial modeling of a particular strategy repeated frequently through the testimonies: that of moving to high ground to escape floodwaters. This kind of ephemeral response may leave behind limited material evidence but has implications for the preservation of ancient sites in the past and present. Here we describe our methods and results of this trial, with our own observations on opportunities for expansion with additional data or refined approaches, and implications of this work for the archaeology of El Niño.

Background: Environmental Setting, Cultural Context, and Previous Research

The Lambayeque Valley is rather a complex of three major river valleys–the Lambayeque, La Leche, and Motupe–that are hydrologically connected in their lower reaches and have a shared coastal plain totaling over 200,000 hectares. In the early sixteenth century, the Lambayeque Valley was a culturally rich and productive region with monumental administrative centers, industrial manufacturing of pottery, textiles, and metalwork, and intensive farming of coastal river valleys through extensive irrigation works. These activities have long histories in the Lambayeque and adjacent valleys, with incipient canal systems since ca. 2500 BC (Dillehay et al. 2005), monumental architecture since ca. 2150 BC (Alva Meneses 2008), textiles and ceramic production since ca. 1800 BC, and metallurgy no later than the first century AD (Alva and Donnan 1993).

For much of human occupation of the Lambayeque Valley, communities were independent to loosely organized but frequently shared ethnic and religious identities with others in the Lambayeque Valley Complex and the broader north coast. Lambayeque groups developed greater complexity in the first centuries AD, beginning with the contemporaneous Gallinazo and Moche cultures from ca. 100 to 750 AD followed by the Lambayeque, or Sicán, culture from ca. 750 to 1375 AD (Shimada 1990, 1994; Zevallos Quiñones 1989). Although the Lambayeque culture expressed changes over time in iconography and the locations of administrative centers, archaeological evidence suggests architectural forms, settlement patterns, and the administration of irrigation systems remained similar, even as land use and industrial activities intensified (e.g., Hayashida 2006; Shimada 1990).

This continuity–especially political changes in irrigation practices and settlement patterns–began to change with a series of conquests, first by the neighboring Chimú ca. 1375 AD, the Inca ca. 1470 AD, and the Spanish beginning in 1532 AD. As part of its colonization of Peru, Spain replaced reciprocal tribute relationships of the Inca Empire with the encomienda system, in which Spanish encomenderos were authorized by the colonial government to force tribute in the form of labor or goods from native populations under their charge. A parallel process was that of the reducción, a process of relocating and organizing the Indigenous population into new settlements where they could be more easily controlled and "improved" (e.g., through the imposition of Spanish urban order and religious conversion, VanValkenburgh 2021).

The people of the Lambayeque Valley have a long history of experience with El Niño, which has been recurrent on the North Coast for nearly 6000 years (Sandweiss et al. 1996) and at a modern or near-modern frequency of about one event every 2-7 years since around 1000 BC (Sandweiss et al. 2001). El Niño, the warm phase of the El Niño-Southern Oscillation (ENSO), has several modes (Sandweiss et al. [2020] summarize modes relevant to Peru). In the North Coast of Peru, including the Lambayeque Valley, both the canonical Eastern Pacific mode and the Coastal mode of El Niño produce significant warming of sea surface temperatures that in turn results in mortality or out-migration of fish, marine mammals, and seabirds and intense rainfall, flooding, and mudflows over land. Eastern Pacific El Niños also produce drought in the highland source areas of coastal rivers. Historical and archaeological research has shown that Eastern Pacific and Coastal El Niños, which are thus far indistinguishable in the archaeological record (Sandweiss et al. 2020), manifested in similar ways in the past, with sometimes considerable impact on past societies (e.g., Huertas Vallejos 2001; Sandweiss et al. 2007).

Archaeological work in the Lambayeque Valley confirms recurrent experiences of El Niño events throughout the millennia, from alluvial erosion and laminated sediments evidencing rainfall and flooding at monumental centers (e.g., Craig and Shimada 1986; Heyerdahl et al. 1995) to the damage and reconstruction of irrigation canals (e.g., Huckleberry et al. 2012) and the alluvial deposition of silt over agricultural fields (Nordt et al. 2004). Shimada (1990, 1994) found evidence of flooding associated with destabilization of the Moche civilization and abandonment of their administrative center at Pampa Grande around 750 AD. Shimada (1990) also identified evidence of flooding associated with the burning and abandonment of the Sicán precinct at Batan Grande around 1100 AD, corresponding with the end of the Middle Sicán period (~900-1100 AD). Sandweiss and Maasch (2022) compared patterns of abandonment in the Lambayeque Valley with paleo-ENSO records and found correlation between these abandonments and periods of high intensity El Niño events, although the evidence was less conclusive for the end of Middle Sicán at 1100 AD.

Archaeological work across Peru's coast more broadly has demonstrated that over millennia of experiencing and recovering from ENSO disasters, people developed knowledge about the phenomenon and trialed new ways of preparing for, surviving through, and recovering from events (e.g., Sandweiss and Maasch 2020 inter alia). However, Spanish colonization beginning in 1532 AD disrupted traditional relationships with land and water and the capacity of Indigenous inhabitants to put traditional knowledge and practices into action. As Sandweiss and Maasch (2020) review, inhabitants of the Lambayeque Valley were contending with significant population loss and considerable changes in settlement patterns, power relations, and economics. New reducciones placed the Indigenous population in the floodplains, often adjacent to rivers and directly in the path of El Niño flooding. Traditional reciprocal tribute relationships that held leaders accountable for community well-being had been replaced with a unidirectional flow of goods to Spanish administrators who had no knowledge of local conditions and variability and who did not understand, appreciate, or apply Indigenous knowledge about El Niño.

This situation left inhabitants vulnerable to severe flooding, which occurred in 1578 AD when a major El Niño devastated the North Coast and the new reducciones, as well as crops, food stores, and irrigation infrastructure. The rains encouraged diseases and agricultural pests such that farmers were unable to harvest for several years, contributing to widespread famine. Meanwhile, encomenderos continued to enforce tribute payments and required inhabitants to rebuild major infrastructure before tending to the needs of their families and communities. These conditions prompted Indigenous leaders to collectively petition the Real Audiencia (royal authorities) for tribute relief.

Testimonies from the resulting adjudication were collected in 1580 AD by a royal inspector and scribe, Don Francisco de Alcocer, from a dozen communities across the North Coast, including seven in the Lambayeque region: Cinto/Chiclayo, Lambayeque, Ferreñafe, Túcume, Íllimo, Pacora, and Jayanca. Alcocer structured his interviews around two questionnaires: one for witnesses called by the encomenderos and a separate one for witnesses for the Indigenous leaders of each community. The interviews were structured to validate or refute the competing claims made by the Indigenous leaders and encomenderos (Copson and Sandweiss 1999). Although we do not know the exact wording of the questions–we have only the witnesses transcribed responses–they were primarily concerned with establishing the conditions influencing the ability of Indigenous people to pay their tributes and taxes. Did people lose their fields because of the rains? Did they lose their livestock? Did people flee the town? Were the canals broken? What were crops worth before and after the rains? This format resulted in a high degree of repetition in the reported types of impacts and responses, but witnesses also varied in their details, often going beyond the scope of questions to try and tell their experiences of the event.

Historians and ethnographers have drawn from the testimonies since at least 1906, when Marco A. Cabero published a small portion in the Revista Histórica (Cabero 1906). Brüning (1917), Rostworowski (1983) and others drew on Cabero's work or on the original documents at various times, but it was Huertas Vallejos (1987, 2001) who completed transcription of the known testimonies and published them to foster broader scholarship. In his presentation of the material, Huertas Vallejos provided historical context about sixteenth-century Indigenous populations, the encomienda system, and the historicity of El Niño events.

Wendy Copson (ca. 1990s) examined testimonies from the villages of Lambayeque, Túcume, and Ferreñafe to better understand the coping mechanisms the Indigenous population employed before and after the event and compare these to existing information on the effects of ENSO on northern Peru. She identified the following themes among their responses: relocation (for example, to higher ground or to other villages), rebuilding (e.g., repairing canals), and refinancing (e.g., selling livestock and goods at lower prices while keeping the prices of key resources high).

Building on this Copson and Sandweiss (1999) further examined how ancestral knowledge was thwarted by colonial rule. For instance, people traditionally lived in the margins of valleys away from the floodplains. However, by the mid-sixteenth century, Spanish colonizers began removing indigenous communities from these prime areas to forced resettlement villages called reducciones. After the event, rather than focusing on rebuilding and strengthening community structures and services, indigenous communities were forced to provide labor and continue to pay tribute, placing new demands on how they prioritized their energy to levels beyond simply surviving.

Expanding this work even further, Maasch and Sandweiss shed light on the opportunities that ENSO provides, showing the flipside to what we commonly frame as a natural disaster. In their analysis, they examine Copson's work under this new lens and identify the following coping strategies: relocation, building/rebuilding, replanting, refinancing, foraging, and emotional responses. Their most recent work is part of a larger trend in Peruvian archaeology to view El Niño from a resilience perspective that recognizes the agency of past communities in their responses and seeks to understand social and natural processes and interactions that influenced resilience through time (e.g., Caramanica et al. 2020).

Methods

Our approach to the Alcocer testimonies was in part modeled after one used by historical geographer Ruth Mostern in her historical gazetteer of the Yellow River in China (Meeks and Mostern 2014; Mostern 2021). A gazetteer is a collection of places that describes their location and notable attributes. In everyday ways of thinking, people tend to consider a place (e.g., a town) as consonant with the physical space it occupies. However, over the course of history, a town may grow, shrink, shift, or move altogether, even as its name and identity remain the same. In other cases, the name of a place may change even as its location stays the same. It is therefore analytically useful to separate places from their spatial component yet have ways of linking them. This can be accomplished through the use of a relational database with a spatial component based in a geographic information system (GIS). A relational database is a collection of data frames (i.e., tables) wherein specific entities or observations can be linked together across tables by the use of shared attributes or alphanumeric keys.

We developed such a database for storing information of interest from the Alcocer testimonies, with individual tables organized around the following themes: witnesses, character of the El Niño event, impacts, and responses (**Figure 1**). Witness characteristics such as occupation and age provided evidence to support inferences about a witness's social status or previous experience with El Niño events. But also, given the testimonial nature of the document, each historical observation is linked to a specific witness, and therefore the witness's name was a useful key to link different kinds of observations and allow for cross-table analysis, such as whether social status influenced the types of impacts or responses a witness focused on in their interview.

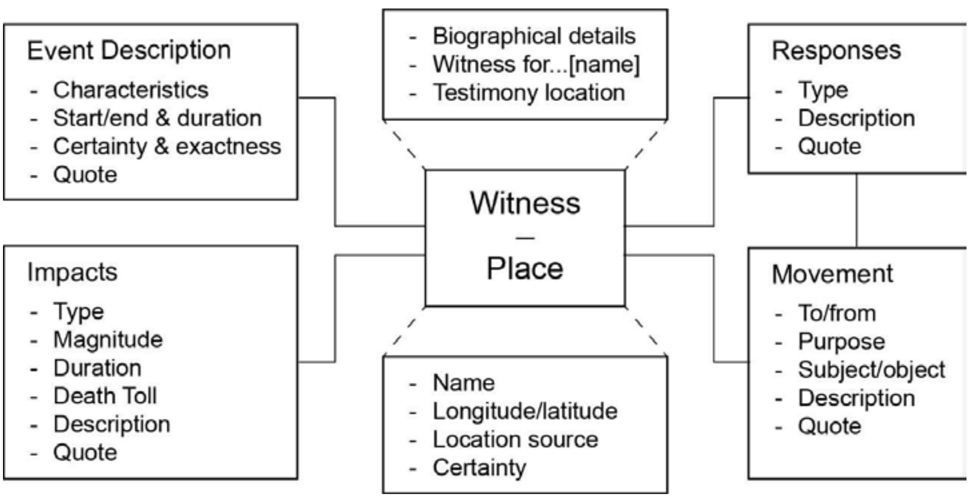

Figure 1. Relational database model.

In this analysis, however, our primary focus was on descriptions of the character of the El Niño event in a given location (e.g., did the witness describe rainfall, flooding, or both), the types and character of impacts described by the witness, and the actions the witness described people taking in response to the event. For each unique observation made by a witness, we recorded the location of the observation, relevant details about type or magnitude, notable quotations, and any notes the researcher wished to append. When available, we recorded quantitative data such as the duration of rainfall or the number of reported deaths along with a categorical assessment of the witness's exactness or certainty.

Initial reading indicated that movement –mainly of people but also of goods and money–was an important component of response. We tracked this particular kind of response in a separate table in which each movement is associated with an origin, a destination, the subject of the movement, and its purpose. This essentially produced a network data frame, wherein various nodes (in this case towns and other places) are connected by multiple instances of movement, allowing for various kinds of network analysis and visualization, which we've only begun to explore here.

Alcocer's witnesses were asked to provide testimony based on their own observations of the places where they experienced the El Niño and its aftermath. These places provide a secondary linkage between tables, making it possible to query the database for specific locales and examine the data for patterns. It also becomes possible to import observations into a GIS and map their spatial distributions–to see how physical manifestations of the El Niño, its impacts, and social responses correspond and interact with the landscape. Defining this landscape in the GIS became an extension of the data collection process.

We used ESRI's ArcGIS Pro software to create the spatial component of our database, which consisted of point locations for various places named in the testimonies as well as landscape features and archaeological sites. We subsequently used the same software to visualize and explore the data, conduct spatial analyses, and generate maps.

Point locations were assigned to discrete places named in the testimonies and were categorized by one of three periods: modern, ca. 1578 AD, and prehispanic. We assigned each point a degree of certainty (high, medium, or low) based on our confidence in the source and/or our interpretation of that source (e.g. textual descriptions of former townsite locations). Initially we focused mainly on locating places where testimonies were collected. Through secondary historical literature and field reconnaissance of historic architecture and archaeological remnants, we confirmed that the modern towns of Chiclayo, Lambayeque, Ferreñafe, and Jayanca have developed more-or-less in situ since the 1578 AD El Niño. The point locations assigned in the GIS correspond to the locations of 16th century churches in each of these towns, which fronted plazas that formed the center of town life. The towns of Túcume, Pacora, and Íllimo, on the other hand, were destroyed in the 1578 AD El Niño and either were or may have been rebuilt in new locations. The site of Túcume Viejo is well-known, located very near the archaeological site of Túcume. The original townsites of Pacora and Íllimo, however, remain unknown to us[1]. Towns in the Lambayeque Valley were attributed with their 1575 and 1602 populations (after Cook 1982). The point layer of places facilitated the creation of a "movements" layer of line features connecting the origins and destinations described in the movements network data frame.

Because of the importance of water to the story of the 1578 El Niño, we also created a layer of rivers, canals, and quebradas. This layer draws on numerous sources, including modern river channels and irrigation networks (Gobierno de Lambayeque 2013a), archaeologically recorded canals (Huckleberry et al. 2012), ethnohistoric research into late prehispanic and early colonial water management (Netherly 1984), local geomorphology (Gobierno de Lambayeque 2013b), and a terrain-based hydrological model. We used the Aster Global Digital Elevation Model V003 (Abrams et al. 2020) to represent the topography of the study area and ESRI's hydrological modeling tools in ArcGIS Pro to create the hydrological model, using a flow accumulation threshold of 10,000 cells (see O'Callaghan and Mark 1984; Tarboton 1997; Tarboton and Ames 2001 regarding the use of digital elevation models to create channel networks; see González-Moradas and Viveen 2020 for an evaluation of different digital elevation models in the Andes). The hydrological model was mainly used to define quebradas, most of which are topographically constrained and have likely only changed course within the confines of associated landforms over the past 500 years. This level of accuracy was sufficient for our purposes in this analysis. As with the place data, we assigned a certainty value to each water feature based on our confidence in its routing and/or contemporaneity with the 1578 AD event.

The final component of the GIS was a point layer of archaeological sites obtained from Peru's Ministry of Culture (Ministerio de Cultura 2015). We refined this layer to reflect prehispanic habitation sites by removing any obviously historic period sites and buildings as well as prehispanic infrastructure like roads and canal segments. These data reflect only what has been preserved, identified, and reported to the Ministry of Culture and therefore must be assumed incomplete; however, this layer contains hundreds of archaeological sites in the Lambayeque Valley and is our best approximation of former settlement patterns.

Spatial analysis of the data took two forms: exploratory mapping of spatial patterns and geospatial modeling via cost surface analysis. The first phase began with construction of the geospatial datasets – for example, seeing how towns related to various water features, archaeological sites, and the overall terrain as the data layers were brought together. This process involved joining testimony data to their associated places, thereby allowing us to see and map the locations of specific types of effects and responses. The physical relationships between towns and the landscape also suggested patterns of vulnerability and challenges people may have faced in trying to reach safety during the flooding, such as distance from areas of high ground and circumscription by rivers and canals that could have been dangerous to cross if flooded. This led to the geospatial modeling of least-cost paths to potential places of refuge.

In spatial analysis, least cost analysis (LCA) predicts the most effective movements across a landscape by accounting for various "costs" associated with moving across particular areas. It is a useful tool for understanding, visualizing, and even predicting (with varying levels of certainty) human relationships to and interactions with their environments (Surface-Evans and White 2012). LCA employs Zipf's Principle of Least Effort (Zipf 1949: 7) which generally assumes that humans tend toward efficiency in many aspects of their behaviors as a means of resource preservation, including the preservation of energy or effort. This can be modeled in GIS by developing parameters based on observed and assumed "costs" and used to predict potential areas of human activity (e.g. Anderson and Gillam 2000, Gustas and Supernant 2016; Howey 2011). The method begins by creating "cost surfaces": the landscape is divided into a grid (a raster) wherein cell values represent the cost of a certain activity in that location. This can be done multiple times, reflecting different kinds of costs, and the individual grids are then weighted and combined into a single cost surface. LCA then uses the aggregated cost surface to predict paths that present the fewest costs to a traveler between a given starting point and destination.

We developed our cost path model using Spatial Analysis tools in ArcGIS Pro by establishing parameters we thought might increase the "cost" of traveling from the reducciones to places of safety. We defined these potential places of safety based on the locations of huacas, which are prehispanic monumental earthworks that are typically elevated above the surrounding terrain and were often built on natural rises. We considered potential hazards that an inundated landscape might present and determined that distance, slope and the presence of rivers or other water features were the variables available to us with the greatest potential to affect the cost of a path to refuge. We determined that distance between reducciones and huacas would be a greater limiting factor than slope, and this variable was weighted at 0.6 (60% of the total) while slope was weighted at 0.4 (40% of the total). Our rationale is that when fleeing, one is likely most concerned with getting to the nearest refuge. Water features were then input as barriers, forcing the model to reroute paths around them.

The analysis ultimately produced the least cost path between each reducción and nearby huacas with a qualitative assessment of difficulty (see Results). It should be noted that cost path calculations do not take into account actual traversable paths between locations and are rather a measurement of straight-line paths from point A to point B. Further, any measure of efficiency and/or effectiveness of a path in the context of our analysis relies on the assumption that the people in question have a sufficient amount of familiarity with the landscape they are interacting with.

Results

We coded a subset of 14 testimonies, two each from the towns of Lambayeque, Ferreñafe, Túcume, Íllimo, Pacora, Jayanca, and Cinto/Chiclayo. From these, we recorded 28 distinct descriptions of the El Niño's physical manifestation (e.g., rainfall or flooding), 140 descriptions of impacts on communities, and 97 unique descriptions of communities' responses. We also identified 108 instances of movement of people, goods, or money. This database formed the basis for our analysis, as described below.

Experiences of Disaster

Witnesses described both destructive rainfall and catastrophic flooding during the 1578 event. Many witnesses described 40 days of rain, while others said two months and another reported variable rainfall over a period of 90 days. Descriptions of "40 days of rain" (Alcocer 1987 [1580]:69, f. 251r., II; 80, f. 263v., II; 119, f 309v. II) bear similarity to biblical floods described in the book of Genesis and could reflect the influence of religious instruction on people's experience of the event. Many witnesses describe the rivers and canals "leaving their banks," while some heard Indigenous community members tell that "the sea stretched out" (e.g., Alcocer 1987[1580]:40, f. 218v./r., II). Whether from rainfall or flooding, nearly all witnesses told Alcocer that buildings were destroyed, that canals were "broken" or "stolen," and that fields of crops were washed away. We integrated descriptions of how an event unfolded in particular places into the GIS, which allowed us to form a picture of the geography of the 1578 AD El Niño: where flooding occurred, the intensity of damage across different communities, and patterns of destruction within communities (**Figure 2**). For example, one witness from Lambayeque described,

> "When the river entered the village, it toppled the houses of the priests, which were very nice, and the houses of the cacique and those of the encomendero and of the community…with the water that rained from the sky fell the houses of this witness, which were in the high parts of the village where all of the Spaniards lived, and likewise the inn and all the houses of the indians, all of them collapsed, and the church and the other houses of the indians, all of them collapsed, and the church…fell." [Alcocer 1987(1580):54, f. 235v., II; translation by authors][2]

Statements such as these not only portray the extent of damage, which in some communities was complete, but also give clues about how people were organized across the landscape, and in turn, their vulnerability to particular kinds of impacts. The indigenous population of Lambayeque and their community buildings were all in lower portions of the town that became flooded, along with houses of some, if not most priests, the cacique (Indigenous leader), and, interestingly, also the encomendero–perhaps to have greater oversight of those in his charge. The witness was also a priest but lived with other Spaniards in the higher parts of the town. Although houses and buildings in the floodplain and on high ground were all affected, the duration of inundation, potential to salvage belongings or building materials, and the capacity to rebuild likely varied between these geographies.

Descriptions of canal damage, paired with hydrological modeling used to produce the hydrological layer in the GIS, also allowed us to hypothesize where significant damage occurred to this vital infrastructure (**Figure 2**). Witnesses frequently named major canals when describing the damage or else provided enough context to identify the affected canal. They also sometimes provided the number of locations where the canal was known to have failed. One witness from Túcume described that all of the canals were broken "from the mouth of the river," (Alcocer 1987[1580]: 75, f. 258v., VII) which could be interpreted to mean that headgate structures were destroyed. We complemented these descriptions with flow accumulation values derived from the hydrological model. This metric describes the amount of land surface area that contributes to a given point along a stream channel. Thus, quebradas with higher flow accumulation values at their intersection with a canal are capable of producing a greater amount of stream flow at that point and may be more likely to cause damage during a flood event.

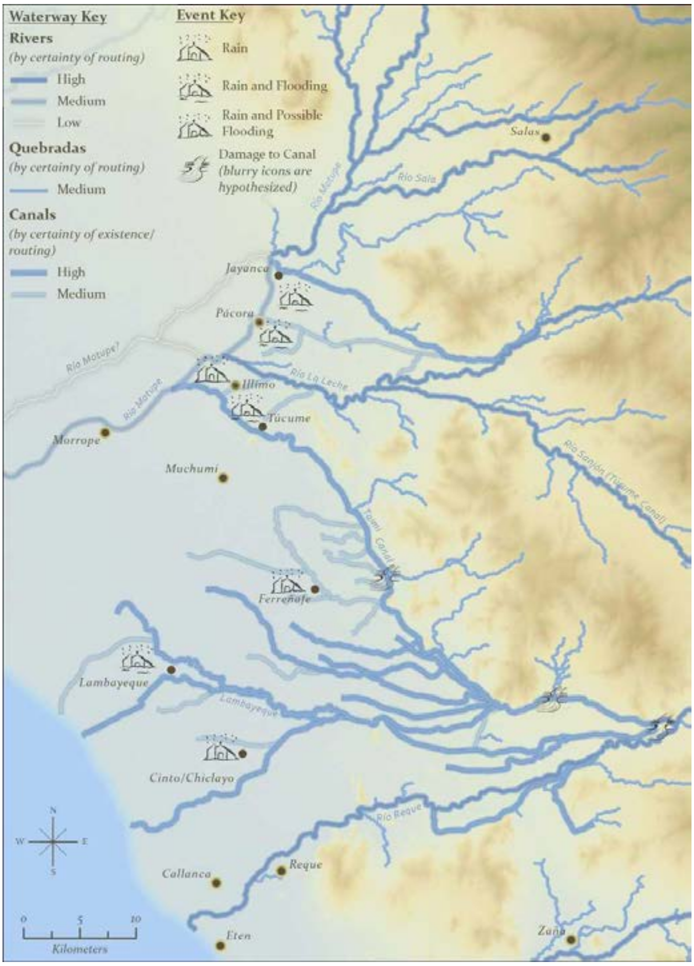

Figure 2. Visualization of rainfall and flooding in the Lambayeque Valley from testimonies.

That said, flow accumulation values provide only a first approximation of the potential for flooding and damage to infrastructure. Rainfall and surface runoff can vary from catchment to catchment depending on storm characteristics, topography, geology, soils, and channel geometry. Canal engineering and construction at quebrada crossings would have also influenced vulnerability to flood damage. Our approach here could be expanded to include more detailed geological, topographical, and climatological information to better predict where ancient canals were most likely to have been damaged during El Niño events. This in turn could be used to target archaeological investigation of topics such as canal engineering and resilience, the life history of particular canals, or the susceptibility of ancient canal systems to damage or disruption from El Niño flooding.

Descriptions of the impacts of the 1578 AD El Niño were not limited to flooding or the loss of buildings and infrastructure. Nor were the impacts limited temporally to the hours, days, and weeks following the rains. Rather, witnesses additionally described the loss of crops, livestock, food stores, and the topsoil of their fields. Beyond the initial loss of crops, farmers experienced successive failures due to saturated soils and pests, as discussed further by Sandweiss and Maasch (2020). Lambayecanos were displaced for months afterward, some living in makeshift shelters built of sticks and blankets atop hills and huacas. The testimonies describe how famine and disease continued to ravage these communities in the two years after the El Niño. Nearly all testimonies we reviewed commented on the loss of life, even though this does not appear to have been part of the questionnaire (Copson and Sandweiss 1999).

Responses to Disaster

The Indigenous inhabitants of Lambayeque employed various strategies to preserve their lives and recover their livelihoods in the aftermath of the El Niño. As seen in previous work, we noted that replanting, building/rebuilding, foraging, and what has been previously defined as refinancing were common responses. We also identified responses outside these categories, including evidence of mutual support between communities, breaking of religious taboos, and appeals to religious beings (**Table 1**). These newer additions fill in some of the "gaps" identified by Copson (ca. 1990s), namely, systems of reciprocity.

Table 1.
Comparison of previously identified response types and present categorization.

Copson (ca. 1990s)	Sandweiss and Maasch (2020)	This Study
Relocation	Relocation	Relocation (short- and long-term)
Rebuilding	Building/rebuilding	Building/rebuilding
	Replanting	Planting/replanting
Refinancing	Refinancing	Leveraging (under duress)
	Foraging	Foraging
	Emotional responses	Emotional responses
		Inter-village aid
		Appeals to religious beings

Sandweiss and Maasch (2020) refined Copson's earlier category of "rebuilding" responses by noting that Lambayecanos sometimes rebuilt infrastructure that existed prior to the El Niño, such as irrigation canals or public buildings, but also engaged in the construction of new features–raised platforms, new canals, new agricultural fields– to manage new and altered conditions. Sandweiss and Maasch (2020) also highlighted replanting of agricultural fields as a separate category of response, one that was often done to appease Spanish demands for tribute crops that had been destroyed in the flooding. However, as noted above, elevated soil moisture, pest outbreaks, and broken canal systems often thwarted such attempts. In our review, we noted that some witnesses described different kinds of plantings that were more responsive to emerging conditions, such as trying alternative crops or planting within non-functional irrigation canals and new fields placed to take advantage of moisture conditions. These kinds of responses echo field systems Caramanica et al. (2020) have observed archaeologically in the Chicama Valley and employed in the Lambayeque Valley in response to the 2017 El Niño.

Our emphasis on place showed that short-term and long-term relocation was one of the most common strategies and that movement was a key component of some of the previously discussed categories, including foraging, leveraging (under duress), and inter-village aid. Short-term relocation, on the order of days to months, was especially common as a response to the physical impacts of the rain, such as fleeing to high ground to escape flooding or subsequent residence in temporary encampments. This type of movement was the focus of our LCA, described further below.

In other cases, movements were portrayed as permanent relocations to another town or city, often in a different valley, and sometimes to major cities as far as Lima, nearly 700 km away. Many testimonies described people going to the towns of Motupe and Olmos, 30 and 45 kilometers upriver of Jayanca. That these towns are mentioned so frequently and that Alcocer did not collect testimonies from either suggests these villages may not have experienced the same severity of impacts. This makes sense—El Niño rains dissipate as one moves further (and higher) inland. However, it is unlikely these small towns could have provided for all of those displaced from the lower valley. Many others are described as fleeing to the highlands, a strategy that echoes archaeological patterns of movement between the coast and highlands of southern Peru during times of environmental stress (Fehren-Schmitz et al. 2010).

Returning to witness testimonies of short-term relocation to higher ground, we tested the use of LCA to hypothesize the most likely places where people sought refuge. We began with a recurring reference of people moving to the huacas and high hills during El Niño flooding (Alcocer 1987 [1580]; Sandweiss and Maasch 2020) and modeled least cost paths between the reducciónes and nearby huacas, as described in the methods and shown in **Figure 3**.

The results of the LCA, as expected, show that in most cases, huacas that are nearest to a reducción were easier to reach than those further away, and some paths increase in difficulty with distance. Some towns had a number of viable paths to reach high ground, whereas others were limited to only one or two nearby huacas. The inclusion of water features as barriers to movement significantly alters potential pathways to safety. The reducción of Ferreñafe, for example, is nearly circumscribed by canals, severely limiting possible places of refuge from here. Our analysis treated all water features–rivers, canals, and quebradas–as barriers, but a refined analysis might take a more nuanced approach. That is, a swollen river or major canal would have presented a greater risk to crossing than a smaller lateral canal.

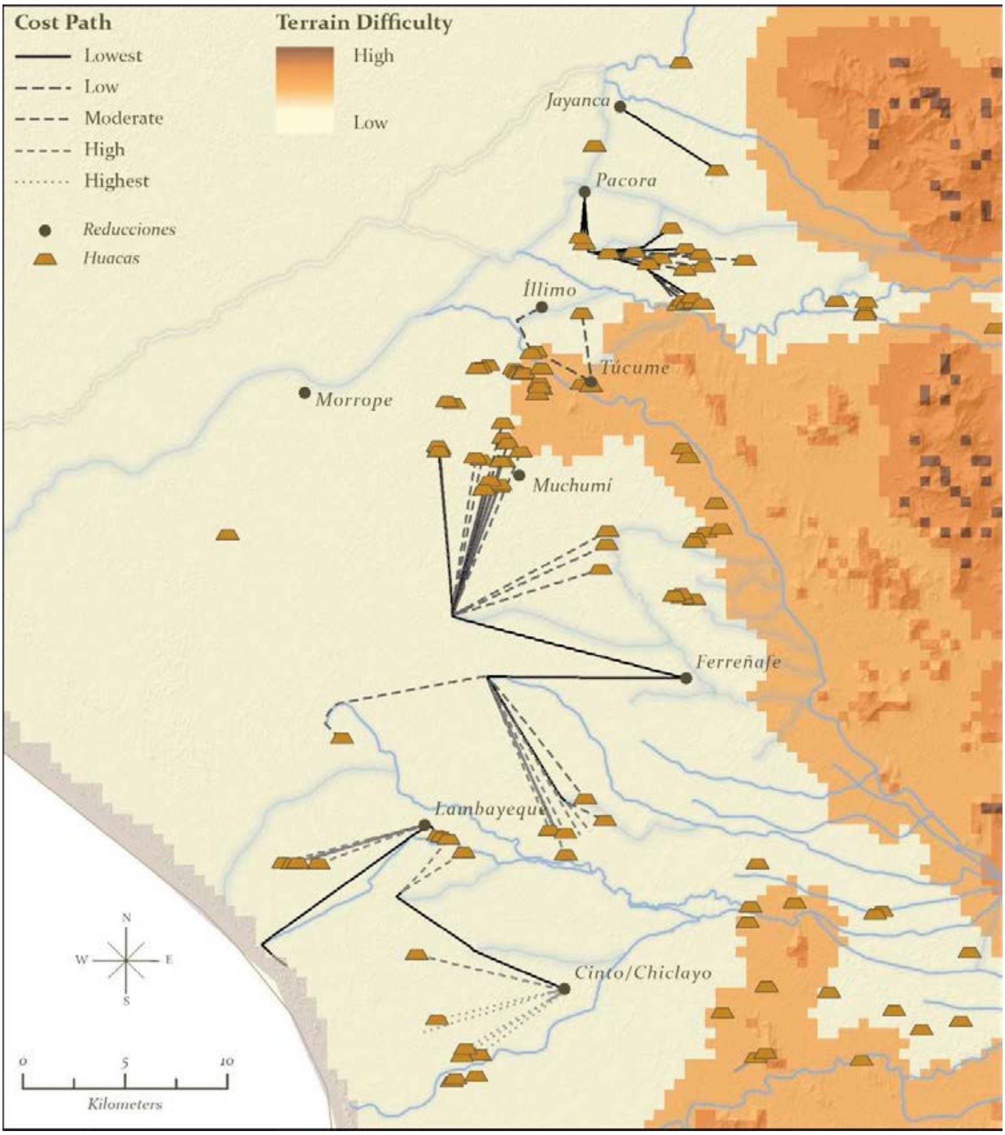

Figure 3. Least cost path model for potential routes from *reducciones* to *huacas*.

As with the identification of likely canal ruptures described above, we used witness testimonies to develop and refine the LCA. For example, several witnesses described the distance between reducciones and the places where inhabitants sought refuge, using colonial-era terms and relative comparisons that require interpretation. One witness described that, at the time of the rains, people from Jayanca fled and climbed a sandy hill or dune "two shots of an arquebus" from the pueblo (Alcocer 1987[1580]:111, f. 299r., VI). Others used leagues; however, the term "league" had multiple definitions and associated lengths in Spain's colonies in North America, (Chardon 1980), and the same is reasonably expected for Peru. Based on the context of the testimonies and the reported personal backgrounds of witnesses in question, we assume they were referring to the "common league," which is equivalent to about 5.5 km. The greatest distance reported in the testimonies we reviewed was 4 leagues, and we limited the LCA analysis accordingly to 22 km. Upon reflection, this seems an unlikely distance that one would have traveled in an immediate search for high ground but may describe subsequent relocation to temporary shelter. This example illustrates some of the opportunities and challenges of integrating historical textual sources into geospatial analysis, even in cases such as this where the context of the text–interviews about losses, recovery, and the capacity to pay tributes–is well-aligned with our research topic.

Modeling potential pathways to high ground was not just an idle exercise in geospatial modeling and the results have several potential applications in archaeology. Although the occupation of huacas and high ground was ephemeral in some cases, witnesses also describe people living in these encampments for months, with potential for the accumulation of cultural deposits associated with this use–especially in cases where reducciones were largely destroyed by the El Niño. Witnesses describe residents of Íllimo living on a small nearby hill for two months after (Alcocer 1987[1580]:89, f.274r/v. VI), those of Pacora for three months (Alcocer 1987[1580]:104, f.291r/v. VI), and the people of Túcume for six months (Alcocer 1987[1580]: 75 f. 258r., VI). The model may be used in combination with the testimonies to hypothesize where archaeological deposits associated with these occupations may be found, deposits with the potential to address research questions about lifeways and coping strategies in the aftermath of El Niño. Alternatively, the model might serve to hypothesize which huacas have been used as refuge and therefore subject to intermittent, recurring human disturbance from this use or that are at risk of such disturbance in future El Niños. In the latter case, the model may benefit from the inclusion of additional variables in the cost surface analysis such as modern transportation networks and land use, which may influence how people seek and move toward high ground.

Discussion and Conclusions

Our results from testing spatial historical and spatial analytical methods with a subset of testimonies of the 1578 AD El Niño are encouraging, demonstrating these are productive approaches and there is more to be learned from these documents regarding community responses to the event. The use of the relational database, developed partially in tandem with English translation of the testimonies, resulted in their close and careful consideration in a systematic way. While such coding risks the loss of nuance and forcing of information into etic categories, it also facilitates empirical analysis that can otherwise be difficult to achieve with disparate textual descriptions. This work revealed patterns not reported in previous work, such as the evidence of mutual support between communities and the importance of movement–of people, goods, and money–to community responses to the event. Highlighting movement opens up possibilities for research into the types and densities of relationships among places and other forms of network analysis.

Our focus on place and integration with GIS allowed us to combine textual descriptions with terrain data and incorporate spatial analysis into our work with historical documents. Hydrological modeling of flow accumulation in combination with textual descriptions of the El Niño's transformation of the landscape improves our understanding of people's experiences of this disaster. In the case of the cost path analysis, spatial modeling combined with details from the database allow for a cross-village comparison of the need of and options for refuge. Ferreñafe, almost circumscribed by flooded canals, was also at relatively high elevation and not in a vulnerable river-side position like most of the other reducciones, although the flooding of canals could have still caused significant damage. In contrast, the model shows that the riverside reducciones of Pacora, Íllimo, and Túcume, which were largely destroyed by flooding, could reach nearby huacas along paths of relatively low difficulty.

While the use of LCA is not uncommon in archaeology, our approach was novel in our use of historical texts to build and interpret the model. This method does have its limitations, however, in part stemming from uncertainty inherent in working with historical documents. We must consider the extent to which the context of the interviews influenced the ways witnesses portrayed the events of 1578-1580 AD: the adjudication of tribute relief during a period of extreme hardship and cultural upheaval by witnesses of Spanish and Indigenous descent with their own personal, social, and cultural biases. To what extent may a witness's meaning have been altered or misrepresented between their response, Alcocer's transcription, Huertas Vallejos' transcription, and our translation into twenty-first century English? In cases of Indigenous witnesses who spoke Spanish as a second language or relied on a translator, there is an additional step of translation and changes to meaning. Then there are questions of interpretation. Which league–the legal league or common league–was a witness referring to? When a witness describes people moving to high places, do they mean hills and huacas in the immediate vicinity or do they mean the highlands further inland? Here we must employ the tools of the historian, relying on context and cross-comparison of testimonies to frame our interpretations, and we must consider sources of uncertainty in our interpretations, just as with geophysical sources of uncertainty and other assumptions–for example, the resolution and accuracy of a digital elevation model or imposed slope limitations.

Overall, we feel that the benefits of incorporating historical testimony into spatial analysis outweigh risks of misrepresentation or over-interpretation, when the results are used in appropriate ways. In both cases applied here, hydrological modeling and LCA, the models may be best used to frame hypotheses or in comparative assessments of vulnerability and risk. However, our use of historical texts shows potential to do more than simply contribute to archaeological research questions. Our work found historical evidence for coping strategies, mitigations, and other responses observed archaeologically, such as opportunistic farming (Caramanica et al. 2020) and movement to the sierra during times of stress (Fehren-Schmitz et al. 2010). These findings demonstrate the continuation of and reliance on Indigenous knowledge and practices developed through millennia of experience of El Niño. The details of the testimonies also complement archaeological data, describing people's experiences and decisions in the minutes, days, and months after an El Niño–aspects that may not leave material traces at timescales often too short to be resolved in the archaeological record.

The archaeology of El Niño has shifted from a focus on disaster in the past (Van Buren 2001) to questions of adaptation and resilience with the aim of contributing to mitigation strategies and survival today, especially in the face of climate change that is increasing El Nino intensity and frequency (Cai et al. 2014). Indigenous knowledge and practices, developed over long-term interactions with ENSO, are crucial to this goal as they are grounded in millennia of experience with the ways ENSO interacts with local landscapes. Archaeology also has a role, providing perspective on how adaptations arose and changed through time in particular social and environmental contexts. Bridging the two, ethnohistory also has a role: linking the past to the present and connecting the richness of human experience to the dis-embodied material record.

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Notes

[1] The towns of Pacora and Íllimo are mapped according to their modern location and are attributed as having "low certainty," since we cannot confirm whether or how far the towns were relocated after their destruction in 1578 AD. Other places where we used their modern location as a proxy for their ca. 1578 location are mapped in the atlas as having a "medium" certainty because while we lack information that confirms the town was at the same place, we also lack any information pointing to the contrary.
[2] As transcribed in Alcocer 1987[1580]: "...el dicho rio derribo quando entro en el dicho pueblo las casas de los sacerdotes que estavan en el muy buenas y las casas del cacieque y las del encomendero y las de la comunidad...con las aguas que llovio del cielo se cayeron las casas de este testigo que estaban en lo mas alto del pueblo adonde todos los españles estavan recogidos y ansi mismo el tambo y las demas casas de los yndios todas se drrumbaron y cayeron y la yglesia...se cayo..."

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