Bioarchaeology and El Niño: Identifying the biological signature of disaster

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Abstract

The understanding of how natural disasters affect population health is an integral part of the study of population dynamics in changing environmental contexts. Part of the difficulty in undertaking studies of this kind lies in being able to identify the bioarchaeological signature of a natural disaster, particularly given that such disasters often strike suddenly, leaving little evidence of their immediate impact even as their legacy is often very dramatic. This paper seeks to establish a framework for bioarchaeologists to utilize in the attempt to identify and track the impact on populations of disasters such as what often accompanies an El Niño Southern Oscillation (ENSO) event. Specifically, this paper identifies the kinds of biological changes that are often seen following an ENSO, including isotopic changes as they relate to dietary shifts, changes in the frequency and nature of trauma, and changes in the frequency of biological indicators of stress. Furthermore, the types of samples needed to identify many of these biological indicators are discussed.

Key words: Bioarchaeology, Peru, ENSO. El Niño, population health

Resumen

La comprensión de cómo los desastres naturales afectan la salud de la población es una parte integral del estudio de la dinámica demográfica en contextos de ambientales en cambio. Parte de la dificultad en la realización de estudios de este tipo radica en ser capaz de identificar la firma bioarqueológica de un desastre natural, especialmente teniendo en cuenta que a estas catástrofes suelen atacar repentinamente, dejando poca evidencia de su impacto inmediato, incluso como su legado es a menudo muy dramático. Este documento tiene por objeto establecer un marco para bioarqueólogos para utilizar en el intento de identificar y rastrear el impacto sobre las poblaciones de los desastres, tales como lo que a menudo acompaña a un El Niño Oscilación Sur (ENOS). En concreto, este documento se identifican los tipos de cambios biológicos que se ven a menudo después de un ENOS, incluidos los cambios isotópicos que se refieren a los cambios de la dieta, los cambios en la frecuencia y la naturaleza del trauma, y los cambios en la frecuencia de los indicadores biológicos de estrés. Por otra parte, los tipos de muestras necesarias para identificar muchos de estos indicadores biológicos se discuten.

Palabras clave: Bioarqueología, Perú, ENOS. El Niño, la salud de la población

Introduction

Numerous researchers have documented some of the health effects of El Niño events on modern populations (Checkley *et al,* 2000; Kovats *et al,* 2003 and Patz *et al,* 1996). Their data provides bioarchaeologists with a foundation for the kinds of biological impacts that might be visible in the archaeological record. A few studies have examined health changes as they might relate to an El Niño event in past populations (White *et al*, 2009), though more research has focused on technological changes and/or cultural responses to uncertain environmental conditions (Manners *et al*, 2007; Dillehay and Kolata 2004; Keefer and Moseley 2004; Moseley 1999).

White *et al,* (2009) examined isotopic evidence for indications of dietary shifts that might correlate with an El Niño event. Their study concluded that the isotopic variation seen in their samples from Pacatnamu represented terms that were too brief to be the result of an El Niño event; however, their data could be consistent with Dillehay and Kolata's (2004) model of anticipatory flexible and opportunistic exploitation of agricultural resources as a cultural response to uncertain environments, such as those presented by El Niño events and periodic droughts. Still other studies have focused on how seasonality and pathology might be reflected osteologically in isotopic analyses (Knudson *et al,* 2006; Katzenberg and Lovell, 1999; White 1993). This paper will attempt to integrate the types of osteological and chemical evidence as well as biocultural responses that might be expected in samples from past populations impacted by an El Niño event.

El Niño and La Niña - ENSO

In order to fully understand the impacts that these events have on population health, it is important to first understand how these events occur and the specific impacts they have on climate. El Niño is associated with the appearance of warm water off the coast of Peru and Ecuador, which can sometimes persist for 12-18 months. This change from cold to warm water in the area disrupts local fish and bird populations and is associated with heavy rainfall on the coast of South America, an area that normally receives little rainfall.

In the 1960s El Niño was linked to the Southern Oscillation, which is the atmospheric component that helps generate an El Niño event. The linking of El Niño events with the Southern Oscillation as oceanographic and atmospheric components of the same phenomenon resulted in the term the El Niño Southern Oscillation or ENSO (Kovats *et al*, 2003). The Southern Oscillation is a fluctuation in air pressure between the tropical eastern and the western Pacific Ocean waters. It is measured by the Southern Oscillation Index (SOI) computed from measurements of the surface air pressure differences between Tahiti and Darwin, Australia (Trenberth et al. 2007).

El Niño events occur with negative values of the SOI, which means that the pressure at Tahiti is relatively low as compared to the pressure at Darwin. Low atmospheric pressure tends to occur over warm waters because the deep convection over warm water transports air resulting in the low pressure and a decrease in the Pacific trade winds. During non-El Niño conditions, the trade winds move water and air warmed by the sun toward the west, which creates an oceanic upwelling that brings cold water to the surface along the coasts of Peru and Ecuador, but when an El Niño event is occurring these trade winds are reduced in strength and the upwelling is subsequently reduced (Trenberth et al. 2007; Kovats et al. 2003).

Additionally, the warm water feeds thunderstorms and this generates an increased amount of rainfall along the coast of South America (Trenberth et al. 2007; Kovats et al. 2003). While the coastal regions suffer flooding associated with the increased rainfall, the Andean highlands experience drought conditions (Tapley and Waylen 1990).

On a global level, temperatures rise by an average of 0.5 degrees Celsius, and while rainfall increases along the coast of South America, it decreases in other parts of the world, such as Australia, creating drought conditions (Trenberth *et al,* 2007; Kovats *et al,* 2003; Tapley and Waylen 1990; Ropelewski and Halpert 1987; Walker and Bliss 1932). When the SOI is positive, it causes ENSO's other extreme, La Niña, which is a cold event.

The effect of ENSO on crop production and weather disasters in the modern world is so well-documented that the global financial markets and insurance industry take seasonal climatic forecasts into account when planning for the next year. Farmers also use the forecasts when taking into consideration whether or not to plant drought resistant crops when drier conditions associated with an ENSO event are anticipated (Kovats *et al,* 2003).

The effect on disasters is also well established. In an average El Niño year, around 35 per 1000 people are affected by a natural disaster, which is more than four times the number of people affected in a non-El Niño year. From a global perspective, droughts, famines, localized intense rainfall and flooding all can have catastrophic consequences for human health (Kovats *et al,* 2003).

ENSO Impacts on Human Health

For those populations impacted by an ENSO event, the consequences for health can be severe. Droughts can lead to food shortages which can have a number of biological effects. Malnutrition and impaired immune systems increase the risk of infection. Additionally, the socioeconomic turmoil created by a food shortage can result in large scale population movement and the interruption of health services, both of which also serve to increase the risk of infection (Kovats et al. 2003; Glantz 1996).

Furthermore, drought in areas where slash and burn agriculture is practiced can lead to uncontrolled forest fires. Every El Niño since 1982 has been associated with fires in certain parts of the world. The smoke from biomass burning can contain pollutants which are harmful to human health (Kovats et al. 2003; Glantz 1996). Intense rainfall and subsequent flooding is associated with both the El Niño and La Niña phases of an ENSO and this has several potential impacts on a population.

The role of temperature and rainfall in the spread of infectious disease is well-documented and numerous studies have documented increased risk for many types of diseases as a result of an ENSO event (Kovats *et al,* 2003; Checkley *et al,* 2000; Dilley and Heyman 1995; Davis 2000). More specifically, associations have been demonstrated between ENSO and mosquito-borne diseases such as malaria, dengue fever and various other types of arboviruses (Kovats *et al,* 2003).

Additionally, in areas where increased rainfall resulting from an ENSO event was followed by a drought (something which happens frequently), increases were seen in rodent populations and in human-rodent interactions, which serves to increase the risk of the spread of rodent-borne diseases such as plague and hantavirus (Mills *et al,* 1999). Studies also demonstrate an association between ambient temperature and the causes of diarrheal diseases, such as *Vibrio cholerae* (which causes cholera) and *Cyclospora cayetanensis* (Checkley et al. 2000).

One study of hospital admissions for Peruvian children living in Lima demonstrated a 200% increase in daily admissions for diarrhea during the 1997-98 El Niño event (Checkley et al. 2000). Clearly, the impact on human health associated with an ENSO event can be dramatic and severe, and there is evidence that past populations were most certainly impacted by this phenomenon.

ENSO Impacts on Past Populations – Political ramifications

The impacts of environmental problems generated by ENSO events have been well documented from a cultural perspective. Dillehay and Kolata (2004) note that cultural responses have often included relocation to landscapes less susceptible to environmental stress, shifting exploitation of local and distant agricultural resources, large-scale population relocation, restructuring of social organization and intercommunity relations, and even state collapse. Many of these impacts have been documented archaeologically.

Less clear, however, are the bioarchaeological signatures of such events. Given what we know about past cultural responses in combination with modern research into the effects of ENSO events on human health, we should be able to construct a model for identifying biological markers associated with changes in disease loads, diet, and residential mobility that accompany the environmental fluctuations created by these climatic events.

Clearly the environmental fluctuations created by ENSO events can and have impacted human access to dietary resources. Changes in rainfall amounts impact agricultural resources and create potentially devastating floods. An inability to respond to such disasters can easily jeopardize political institutions. Steve Bourget argues the sacrifices in Plaza 3A at Huaca de la Luna represent a state level response to an El Niño event .The skeletons of some 70 males predominantly between the ages of 15-40 years old at death were found in mud deposits around a rock outcrop resembling the cerro behind the site. Bourget argues they were sacrificed to stop the torrential rains associated with an El Niño event (Verano 2008).

Verano (2008) notes that the evidence at Huaca de la Luna supports the conclusion that the Moche culture practiced human sacrifice at regular intervals over a long period of time. It is not hard to imagine that a culture which regularly practices human sacrifice would include this activity, and likely a quantitative increase or qualitative change in this behavior, as part of their response to a natural disaster. There is certainly evidence that other cultures, such as the Inka, did just that as evidenced by the sacrifice of the Peruvian child dubbed "Juanita" by the press. Reinhard (1997) argues her sacrifice was likely in response to a volcanic eruption taking place within view of Mt. Nevada de Ampato where the child's body was discovered.

ENSO Impacts on Past Populations - Stable isotope analysis

In addition to evidence associated with ritual practices that might be part of a political response to natural disasters, cultural responses often include an increase in residential mobility and dietary shifts resulting from differential exploitation of resources (Manners et al. 2007; Dillehay and Kolata 2004).

These kinds of changes should result in changes in isotopic signatures in the bone and/or hair of individuals. The basis for stable carbon isotope analysis is connected to the way plants use atmospheric $\delta^{13}C$ during photosynthesis. What are referred to as C_3 plants discriminate more against $\delta^{13}C$ and therefore have lower values, which are expressed as negative numbers in parts per mil ($^0/_{00}$). C_3 plants include grasses, trees, shrubs and tubers. C_4 plants discriminate less against $\delta^{13}C$ and therefore have a less negative number than C_3 plants. C_4 plants include many domesticated species of plants such as maize (Larsen 1997).

Human consumers of either these plants directly or animals that eat these plants maintain the isotopic differences in their tissues. Stable nitrogen isotope analysis is based on how plants acquire nitrogen. Nitrogen fixers "fix" nitrogen from the air and have $\delta^{15}N$ values that are close to 0 $^0/_{00}$. Plants that acquire nitrogen from the soil typically have $\delta^{15}N$ values ranging from 2 to 8 $^0/_{00}$. Each step in the food chain results in an increase in the $\delta^{15}N$ levels by about 3-4 $^0/_{00}$. Thus, it is possible to determine the level of the food chain from which the protein was consumed (White et al. 2009; Larsen 1997).

Marine plants have higher $\delta^{15}N$ values than terrestrial plants by about 4 $^0/_{00}$, and the marine food web contains more trophic levels, which results in higher $\delta^{15}N$ values (10-13.5 $^0/_{00}$) in marine animals as compared to terrestrial animals (White et al. 2009). Strontium is an alkaline earth element, the stable isotope ratio of which is inversely proportionate to the trophic level of the consumer. Thus, plants have higher strontium isotope levels than carnivores (Larsen 1997).

The ratios of strontium reflect local geochemistry signatures. A signature in human bone that differs from the signature found in the valley from which the bones were recovered could indicate recent changes in residence. Additionally, signatures in the teeth were incorporated into the enamel when the tooth was forming and indicate the childhood residence. If tooth samples differ from bone samples, this could also indicate a change in residence sometime during the lifetime of the individual (Larsen, 1997). Thus, analyses of these isotopic ratios can help establish dietary and residential changes.

By utilizing isotopic analysis, White *et al,* (2009) were able to document evidence for shifting exploitation of resources by analyzing stable carbon and nitrogen isotope ratios in human hair from individuals excavated from the site of Pacatnamu, located in the Jequetepeque Valley on the north coast of Peru. They utilized hair samples because bone samples can give only averaged values for food consumption over approximately a 10-year period. The use of hair, therefore, can indicate more short-term dietary changes such as those that might be explained by environmental factors. Permanent dietary shifts that could result from a shift in resource exploitation prompted by an ENSO event would eventually show up in the bone, but these changes in resource exploitation might be difficult to connect to an ENSO event by the time they were visible osteologically.

The hair samples White *et al,* (2009) utilized were cut into 2 cm segments, which represent a growth period of approximately 2 months. In this way, they were able to document short-term dietary shifts reflected by changing isotopic ratios. Their study demonstrated extensive variability within strands of hair from single individuals and they interpreted this as illustrative of the complexity expected from people who are moving frequently and irregularly across a broad landscape that includes both highland and coastal environments. This pattern, they argue, could be consistent with a shifting exploitation of local and distant resources (White *et al*. 2009) that would be expected in accordance with Dillehay and Kolata's (2004) model of anticipatory cultural behavior in response to uncertain environmental circumstances, such as that encountered during an ENSO event. Notably, White *et al,* (2009) utilized isotopic data gathered from the local Peruvian food web in their interpretation of the human data, and Ambrose (1991) argues the establishment of the local food web isotopic signatures is essential before an interpretation of human signatures can be attempted.

Other studies have also demonstrated a link between climate and stable carbon and nitrogen isotope signatures. Heaton *et al,* (1986) demonstrated a link between arid environments and higher $\delta^{15}N$ values (above 10 $^{0}/_{00}$). Ambrose (1991) also tied $\delta^{15}N$ values to the differing ways that organisms get water and their ability to recycle urea, a nitrogenous waste component of urine. His study supported the findings of Heaton et al. (1986) that higher $\delta^{15}N$ values generally occur in arid or drought prone environments, and this is reflected in the levels seen in the animals living in those environments. A different pattern is seen, however, in a modern study of individuals experiencing malnutrition.

Mekota *et al,* (2006) tracked carbon and nitrogen isotope changes in the starvation and recovery phases of patients suffering from anorexia nervosa. They found that $\delta^{15}N$ values dropped as body mass index (BMI) increased. Conversely, $\delta^{13}C$ values increased with increasing BMI. This could mirror what might be seen in populations or parts of populations that suffer malnutrition as a result of an ENSO event. Thus, high $\delta^{15}N$ values and low $\delta^{13}C$ values might be reflecting low BMI associated with malnutrition rather than arid environmental conditions or necessarily a shift in resource exploitation.

Clearly, the utilization of isotopic data has to be carefully interpreted as part of a complex of data that includes local environmental and resource information recovered from archaeological contexts as well as the biological data recovered from the human remains. When considered carefully, however, bioarchaeologists should be able to utilize these data to demonstrate some of the health effects a population encounters as the result of environmental changes such as those associated with ENSO events.

ENSO Impacts on Past Populations – Osteological responses

Other biological impacts that might be visible osteologically include what are known as non-specific indicators of stress and osteological indications of the presence of infectious disease. These include indicators of malnutrition, such as Harris lines, enamel hypoplasia, and indicators of non-specific types of infection, such as periostitis. Additionally, malnutrition that has resulted in secondary vitamin deficiencies might be visible osteologically in the form of osteomalacia, osteoporosis, and the osteological evidence for vitamin C deficiency as defined by Ortner *et al,* (2001).

Increased frequencies of specific infectious disease would also be expected particularly given a context of increased population mobility and cross cultural contact as a result of limited resources, which serves to both weaken immune systems and increase exposure to disease. Thus, bioarchaeologists might expect to see an increase in evidence for so-called “crowd diseases” such as tuberculosis.

Most bioarchaeologists are familiar with the osteological evidence for these kinds of problems. The problem they encounter is in associating these types of bioarchaeological signatures with an ENSO event. Once again, the solution lies in the incorporation of a complex of data that includes a careful analysis of the archaeological context in conjunction with a paleoenvironmental reconstruction. Additionally, it would be necessary to include an osteological analysis of material that pre-dates the ENSO event in question. One would expect to see an increase in the osteological indicators of stress on a population that has experienced the health consequences associated with ENSO events.Furthermore, it would be expected that the osteological indicators of populational stress would be widespread throughout the population rather than limited to only part of that population, as might be seen with social stratification and the resulting differential access to resources.

Conclusion

The identification of a bioarchaeological signature associated with a climatic event such as ENSO relies on an integrated multidisciplinary approach to osteological analyses. First, an analysis of the remains in question must be interpreted as part of a more complete archaeological and paleoenvironmental context. Second, osteological analyses should include pre-and post-ENSO comparisons and both human and animal isotopic signatures from the area in question, ideally utilizing hair and bone samples rather than bone samples alone. Additionally, factors such as social stratification have to be considered carefully to eliminate the possibility that the osteological impacts seen are limited to a portion of the population and the result of differential access to resources rather than a climatic phenomenon that would be expected to more broadly impact the entire population. Finally, evidence for sociopolitical disruption would be expected to include other possible health effects such as an increase in the frequencies of trauma possibly associated with warfare caused by fighting over resources or with an increase in ritual activities that might include human sacrifice. By utilizing a multifocal analysis such as that described here, bioarchaeologists can add significantly to our understanding of the impact of ENSO on human population health and the consequences that impact has for human cultural responses.

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