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REVISED MOCHE CHRONOLOGY BASED ON BAYESIAN MODELS OF RELIABLE RADIOCARBON DATES

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ABSTRACT. The Moche civilization of the north coast of Peru is thought to be the first state-level society in South America. Understanding of the emergence, spread, and decline of this society, however, has been based almost entirely on relative ceramic phases, rather than absolute dates. This article reevaluates Moche political dynamics and intersite affiliations using radiocarbon dates associated with diagnostic ceramic styles. The phases of ceramic styles at individual sites are estimated using Bayesian models of published ^{14}C dates that have passed explicit selection criteria for reliability. The site-specific phases are incorporated into a regional chronology, which adds additional support to the idea that Moche was a collection of independent polities with complex and nuanced relationships. Based on absolute dates, Moche civilization appears to have spanned between cal AD 200–900, with a significant and socially meaningful increase in stylistic homogeneity between cal AD 600–650.

INTRODUCTION

Historical Perspective of the Moche Civilization

The Moche civilization of the north coast of Peru is characterized by elaborately decorated temple complexes, wealthy elite burials, and exquisite ceramics found in over 10 valleys on the desert north coast of Peru. Although it is currently understood that the Moche inhabited this region between AD 1 and 800, these dates are based on relative dating techniques and have not been revised in the light of new radiocarbon evidence. This article presents Bayesian models of critically reviewed, published ^{14}C dates in order to better understand the chronological development and political affiliations between Moche sites through time.

The Moche have long been considered the first state-level society in South America (Bourget cited in Atwood 2010; Stanish 2001). Over the last 15 years, however, it has been established that Moche was not a single homogeneous entity (Castillo and Uceda 2008). Rather, it consisted of at least two major cultural regions of development: the northern region and the southern region, separated by the large Pampa de Paiján Desert. The northern region is currently viewed as a series of independent polities, whereas the southern region is considered by many to have been a single state, basically maintaining the earlier view of Moche statehood but with a contracted territory (Castillo and Donnan 1994; Castillo and Uceda 2008).

Our understanding of both Moche politics and chronology is largely based on an evaluation of similarities and differences seen in ceramics found on the north coast of Peru. Sites with similar ceramics are thought to have been politically or religiously affiliated, and these affiliations have been tracked through time based on the phases of ceramics styles present at each site. However, the biggest problem in our understanding is that there is no definitively agreed-upon criteria for what makes a ceramic or a site Moche; it is largely based on the opinions of the researcher working there. We adopt a definition that Moche was primarily a religious phenomenon that was expressed through a shared set of symbols and messages presented on portable media, such as ceramics, and other art. Sites that engaged with these messages and symbols were likely participating in some way in the Moche ideology. A site from the same time period that did not use these symbols cannot be considered Moche (see Bourget 2010 on Huancaco). The sites considered in this analysis have generally been considered Moche for the last half-century or more (Figure 1). By refining the temporal span of ceramic styles at individual sites, we can begin to infer intersite affiliations and dynamics.

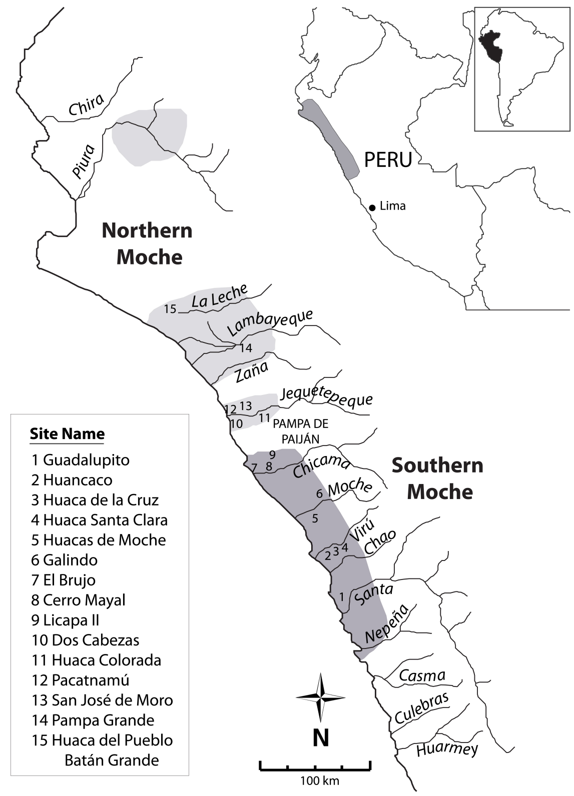

Figure 1 Map of the north coast of Peru showing the Moche region and the sites mentioned in the text. Sites without well-contextualized ^{14}C dates are shown on the map since they are mentioned in the text are Huancaco, Huaca Santa Cruz, Huaca Colorada, and Pacatnamú.

Background on Moche Chronology

Moche chronology was first developed by Rafael Larco Hoyle, the "father of Moche studies," and has long been understood as marked by changes in ceramics over time. Larco was a collector and amateur archaeologist whose family owned a large sugarcane hacienda at Chiclín in the Chicama Valley (Larco 1945, 1948, 2001). He identified a five-phased ceramic sequence (Moche I–V) based on his excavations and collecting in the Chicama Valley. However, Larco never excavated the entire sequence in stratigraphic order at a single site. The five-phased sequence was based on differences in the form and decoration of ceramic vessels. This sequence is applicable to a variety of vessel forms, such as flaring bowls and dippers, but is best identified based on changes in the shape of the spout on stirrup-spout bottles. More recently, other attributes, such as changes in details of iconography on the vessels that correspond to Larco's phases, have been identified (Donnan 1976:54–8; Donnan and McClelland 1999; McClelland et al. 2007; Cole 2012). Calendar dates were assigned to the ceramic sequence, even in the absence of ^{14}C dates (Pillsbury 2001:12; Table 1 and Figure 2).

Larco upheld the idea that the five-phased sequence originated in the Chicama Valley and Moche Valley heartland before spreading to all valleys along the north coast. The particular phase of Moche pottery that first appeared in a valley would mark the relative time period when the Moche conquest occurred. This idea of tracking ceramics, first developed by Larco, became the basis for the Moche single conquest state paradigm that endured until the early 2000s.

Research starting in the 1990s has since revised the single-state model and has demonstrated that there were two regions of Moche cultural development: one north of the Pampa de Paiján and one to the south. It is now believed that the northern region was composed of a series of independent

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polities (Castillo and Donnan 1994; Castillo and Uceda 2008). New research is starting to suggest the same for the south (Koons 2012; Quilter and Koons 2012), but not all scholars have adopted this idea and some maintain that the "Southern Moche" was a unified state. Much of the revision of Moche politics has occurred because of a change in the understanding of Moche ceramics. Investigations at northern Moche sites, such as San José de Moro, have demonstrated that Larco's five-phase ceramic sequence does not work everywhere. A revised three-stage (Early Moche, Middle Moche, Late Moche) ceramic chronological sequence has subsequently been adopted (Castillo and Donnan 1994; Castillo 2001). This northern sequence does not exactly correlate with Larco's sequence, which is still used in the south. For example, Middle Moche in the northern valleys appears to have been contemporaneous with Moche III and IV in the south. Moche V in the south overlapped with Late Moche in the north, although Late Moche endured much longer.

Table 1 Spans of ceramic phases for traditional sequences compared to site-specific spans based on Bayesian modeling of ^{14}C dates. Site-specific spans are the range of calibrated, modeled ^{14}C dates (cal AD) from the start of the 68% highest probability density of the earliest date to the end of the 68% highest probability density of the latest date of a given ceramic phase, using SHCal13 (Hogg et al. 2013) and OxCal v 4.2 (Bronk Ramsey 2009a). Class indicates whether the dates are based on relative ceramic sequences (nonchronometric), modeled ^{14}C dates that passed selection criteria (secure), or modeled ^{14}C dates that failed selection criteria (uncertain). References and model specifics are given in the Appendix (online Supplemental file).

Sequence	Phase	Span (cal AD)	Class
Traditional–Southern	Moche V	550–800	Nonchronometric
	Moche IV	450–550	Nonchronometric
	Moche III	200–450	Nonchronometric
	Moche II	100–200	Nonchronometric
	Moche I	50–100	Nonchronometric
Traditional–Northern	Late Moche	600–850	Nonchronometric
	Middle Moche	400–700	Nonchronometric
	Early Moche	50–400	Nonchronometric
Guadalupito	Moche IV	660–762	Secure
Huaca de la Cruz	Moche IV	685–844	Uncertain
Huacas de Moche	Moche IV	508–731	Uncertain
	Moche III	147–644	Uncertain
Galindo	Moche V	673–764	Secure
El Brujo	Moche IV	601–760	Secure
	Moche III	255–682	Uncertain
	Moche I/II	345–573	Secure
Cerro Mayal	Moche IV	630–849	Uncertain
Licapa II	Moche IV/V	652–813	Secure
	Licapa A	599–672	Secure
Dos Cabezas	Early Moche	458–589	Secure
San José de Moro	Early Transitional	865–968	Uncertain
	Late Moche	764–890	Uncertain
Pampa Grande	Moche V	663–805	Secure
Pueblo Batan Grande	Moche V	600–759	Uncertain
	Moche IV	520–641	Uncertain

Using the ceramic sequences as a relative chronology has created numerous problems that now must be remedied. Many projects forwent any absolute dating methods because it was assumed that the ceramic chronology was accurate at all sites. Furthermore, there was a perceived notion that ^{14}C dates could not achieve the level of precision necessary to distinguish events as well as the ceramic chronologies. Once improved ^{14}C dating techniques (e.g. AMS, consensus calibration curves, Bayesian modeling) became more accurate and affordable, Moche archaeologists began to consider the technique useful. Beginning in the 2000s, ^{14}C dating became more common, and as a result, many inconsistencies in applying the ceramic sequence for chronological purposes became apparent. For example, Lockard (2009) showed that Moche V at the site of Galindo was in use at the same time as Moche IV at Huacas de Moche. Both of these sites are located in the Moche Valley. It was previously assumed that Huacas de Moche was abandoned around AD 600 (when Moche IV was believed to have ceased) and the people moved to Galindo and adopted Moche V wares (Bawden 1996; Moseley and Deeds 1982). However, ^{14}C dates indicate that people continued to use Moche IV ceramics at Huacas de Moche until at least AD 800 (Chapdelaine 2001). The site was not abandoned for Galindo. Moche V wares were used at Galindo between AD 650 and 800 and were, therefore, contemporary with Moche IV wares elsewhere (Lockard 2009).

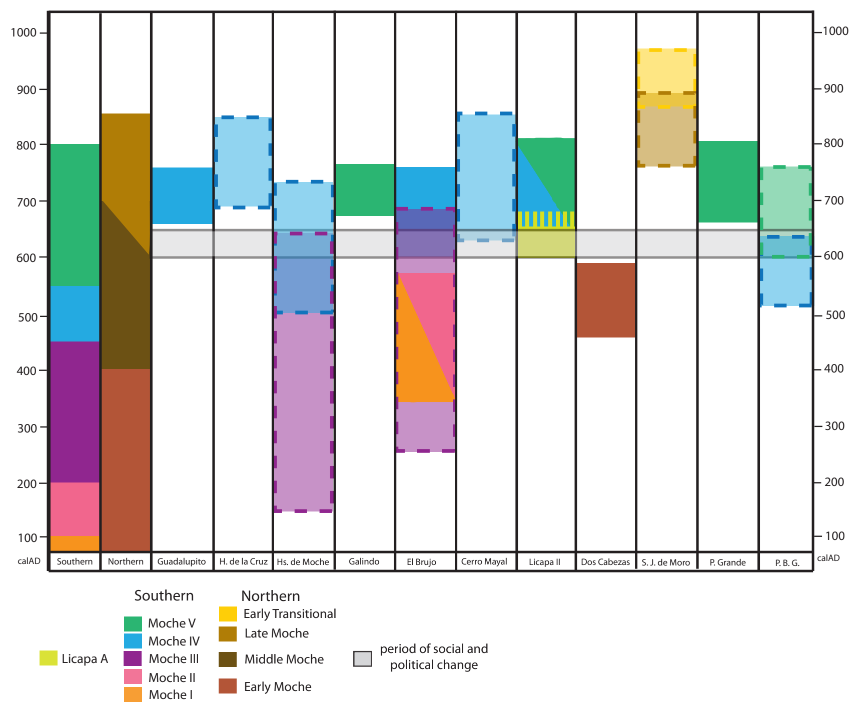

Figure 2 The traditional, nonchronometric ceramic phases for Southern (Larco) and Northern (Castillo and Donnan) Moche sites compared to the spans of ceramic phases at individual sites based on Bayesian modeling of ^{14}C dates. Blocks indicate the span of modeled, calibrated ^{14}C dates (cal AD) from the earliest to latest date in each ceramic phase. Specifically, the spans are defined from the start of the 68% highest probability density of the earliest date to the end of the 68% highest probability density of the latest date, using SHCal13 (Hogg et al. 2013) and OxCal v 4.2 (Bronk Ramsey 2009a). Solid blocks represent ceramic phase spans from secure models based on ^{14}C dates that passed selection criteria. Dashed-faded blocks represent ceramic phase spans from uncertain models that included ^{14}C dates that failed to meet selection criteria. The gray box between cal AD 600–650 indicates a period of likely social and political change in the Moche world. Sites listed from south to north.

Data from Cerro Mayal, a ceramic workshop in the center of the Chicama Valley that produced Moche IV wares, further complicates the relationship between Moche IV and V (Russell et al. 1998; Jackson 2000; Russell and Jackson 2001). Dates from this site mostly fall between AD 550 and 900

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and show that Moche IV ceramics were produced until the end of the Moche era. The dates from Cerro Mayal and Galindo clearly indicated that Moche IV and V ceramics were produced and used at the same time. This implies that the relationship between these two styles was not chronological and suggests that other political or ideological factors were at work.

Recent research in the Virú Valley has also opened up the debate on the expansive state paradigm that was built on ceramic style. Research by Millaire (2010) and Bourget (2010) has shown that sites that were once considered definitively Moche may actually be local variants or not Moche at all,[1] which complicates our understanding of the Moche political landscape.

Additionally, because of a lack of criteria on how Moche ceramics are classified, differences in ceramic style were overlooked for the similarities. For example, over 40 years ago, Donnan (1973:103) noted that Moche IV ceramics in the Santa Valley differ from the Moche IV style in the Moche Valley.[2] Yet this observation has been largely ignored, and Moche IV ceramics in both valleys are discussed interchangeably. To be more accurate, Santa Valley Moche IV ceramics should be considered Moche IV-like.

These examples and other recent work have led to agreement among scholars that the ceramic chronological phases should be viewed as regional, rather than pan-Moche styles (Donnan 2011). This new perspective, however, has opened debate over what these distinct styles represent and imply for Moche politics and/or religion as a whole. Ceramic chronologies are generally constructed recognizing temporal overlaps in styles and that sharp boundaries rarely exist. However, this is often overlooked in practice. One of the main problems for the Moche case is that the overlap in styles and the inconsistent geographic extent of the adoption of these styles is far greater that should be expected when working with a seriation of art styles. The chronological house of cards based on ceramic phases has had great consequences for understanding political relationships between sites and how these developed and changed through time. We are now at a juncture where Moche scholars are charged with reevaluating Moche chronology and overall political organization.

However, the proverbial house of cards has not completely fallen. In some ways, both the Larco (Southern) and the Donnan and Castillo (Northern) sequences can be applied as a general framework. For example, Moche I and II always appear before Moche V and Early Moche always predates Late Moche. The problem is that the boundaries between the phases are indistinct and at no site are all phases encountered. The framework also does not allow for the likely possibility that styles were adopted or abandoned nonsynchronously at different sites.

Reviewing the Radiocarbon Record

Numerous studies over the past decade have shown that many ^{14}C dates are inaccurate, largely due to inappropriate sample selection and pretreatment procedures (Higham 2011). This research has galvanized archaeologists to both improve methods for measuring new dates and to critically review the published record (e.g. Pettitt et al. 2003; Jacobi and Higham 2008; Jöris and Street 2008). In order for a new or published ^{14}C date to be considered secure and included in our reconstruction of

1. Recently, Bourget (2010) has concluded from investigations at Huancaco that Huancaco should be considered a local cultural variation and ceramic style. It may have been influenced by Moche styles of the time, but he contends that the ceramics and architecture do not carry the Moche religious message, and therefore, cannot be considered truly Moche. Likewise, in Millaire's (2010) recent reevaluation of the Huaca Santa Clara he suggests that there is very little, if any, true Moche architecture or ceramics at the site. Some of the ceramics have Moche-like characteristics, but he contends that they are local phenomena.

2. The Moche IV ceramics in the Santa Valley include an almost total lack of black wares, very few fineline ceramics, and ceramics with a much cruder overall surface finish.

the past, it must be demonstrated that the measured carbon reflects the date of the event of interest. In the case of Moche chronology, the events of interest are the timing of ceramic phases at individual sites.

Quality control measures have been proposed to evaluate ^{14}C dates systematically by explicit selection criteria, related to known categories of potential error (Waterbolk 1971; Pettitt et al. 2003; Boaretto 2009; Kennett et al. 2011). Unreliable ^{14}C dates can be attributed to errors in the selection of archaeological meaningful samples and errors during analytical procedures of sample pretreatment and ^{14}C measurement. In principle, analytical errors are easier to identify and ameliorate, although inconsistent results or reporting of results between laboratories raises concern about standardization of methods. In order for the analytical integrity of dates to be assessed, laboratories must report full pretreatment and measurement procedures as well as sample parameters measured along the way (Stuiver and Polach 1977). Unfortunately, such data are often omitted from archaeological publications.

The optimal method of pretreatment depends on the age, material properties, and depositional context of a particular sample (Rebollo et al. 2011; Marom et al. 2013; Santos and Ormsby 2013). Most pretreatment procedures for bone and archaeobotanicals follow an acid-base-acid (ABA) regime (Yizhaq et al. 2005; Brock et al. 2010). If the samples are at high risk for contamination due to great age or other reasons, additional procedures are often applied, such as ultrafiltration for bone collagen (Bronk Ramsey et al. 2004) or ABOx-SC (acid-base-oxidation followed by stepped combustion) for charcoal (Bird et al. 1999). However, we reiterate that the "best method" is one that is tailored, yet explicit, for a given sample.

It is critical that preservation parameters are documented throughout the analytical process. Deviations from known biological ranges or the presence of exogenous molecules suggest contamination. For bone collagen, preservation parameters include C/N ratio, %C, %N, and Fourier transform infrared (FTIR) spectroscopy of bone powder and the organic fraction (DeNiro 1985; DeNiro and Weiner 1988; Yizhaq et al. 2005). Botanicals can be evaluated by microscopy, percent weight loss after pretreatment, FTIR of diagnostic molecular bonds, and thermal stability behavior (Cohen-Ofri et al. 2006; Rebollo et al. 2008). However, this information is unavailable for most published dates.

Evaluating the archaeological relevancy of samples is a greater challenge because the means of assessment are mostly qualitative. "Good" ^{14}C samples come from secure stratigraphic contexts and have a demonstrated association with an archaeological event (Boaretto 2009). Specifically, the measured carbon must have been incorporated into the material from atmospheric CO_2 when the event we wish to date occurred (Bronk Ramsey 2008). Marine resources and wood do not meet this criterion, and will often give a date decades to centuries older than the time of their archaeological use (Kennett et al. 2002). Terrestrial herbivore bone collagen and short-lived plant materials, such as seeds, are more secure samples—provided they are in primary contexts, with low likelihoods of bioturbation or secondary deposition (Boaretto 2009). Association between the ^{14}C sample and event of interest can best be demonstrated with microstratigraphic analysis of the context through methods like micromorphology and sediment characterization (Toffolo et al. 2012). However, while such procedures are the best practice for newly measured dates, they rarely aid evaluation of published dates. For the latter case, we recommend only considering dates with sufficient stratigraphic and contextual information to be independently evaluated.

^{14}C dates (^{14}C yr BP) must be converted to calibrated dates (cal BP) in order to (1) know the absolute duration of events or phases and (2) to relate ^{14}C dates to geologic, climate, or historical records dated by other methods. This is because ^{14}C dates are not actually dates, but dimensionless measurements of the $^{14}C/^{12}C$ ratio in a sample relative to the $^{14}C/^{12}C$ ratio in a standard of known age (Aitken 1990). The concentration of atmospheric ^{14}C in the atmosphere has varied over the past 50,000 yr, and thus age cannot be calculated from ^{14}C by a simple exponential decay function. Rather, the conversion is made by calibration curves that plot ^{14}C concentration over time for samples of known age and the most rigorous curve is based on European tree rings extending back to 12,600 cal BP (Friedrich et al. 2004; Schaub et al. 2008; Reimer et al. 2009).

However, atmospheric ^{14}C concentrations differ between the Northern and Southern Hemispheres and the magnitude of this offset has varied over time (McCormac et al. 2002). The offset is attributed to differences in ocean circulation and atmosphere-ocean CO_2 exchange between the hemispheres (Rodgers et al. 2011). Before AD 1850 (when industrial fossil fuel emissions changed natural distributions), Southern Hemisphere atmospheric CO_2 has been depleted in ^{14}C relative to Northern Hemisphere CO_2, leading to ^{14}C dates 8–80 ^{14}C yr older than the likely true age of Southern Hemisphere samples. Thus, different calibration curves have been developed for the respective hemispheres. The boundary is not sharp and constant at the Equator; rather, the atmospheric hemispheres divide at the Intertropical Convergence Zone (ITCZ), which shifts according to seasons and Milankovitch cycles (Mayle et al. 2000; McCormac et al. 2004). Andean archaeologists have made reasonable arguments for and against use of a Southern curve for different cultural complexes (e.g. Ogburn 2012 for Inca, Marsh 2012 for Tiwanaku). For our time period, the hypothesized southernmost shift in the ITCZ hugs the eastern Andes, and does not reach Moche territory (Sachs et al. 2009). Moreover, near-coastal sites of Peru (all of the sites in this study), receive wind from the south and west, which should be of Southern Hemisphere composition (Ogburn 2012). Therefore, we have chosen to calibrate our chronology with the most recent Southern Hemisphere curve, SHCal13 (Hogg et al. 2013). By providing the uncalibrated ^{14}C BP dates, we enable and encourage others to reanalyze the data with alternative or future calibration curves.

^{14}C dates that pass selection criteria can be combined with other chronostratigraphic information into Bayesian models, which further improve the accuracy and precision of age estimates (Buck et al. 1991; Bronk Ramsey 2009a). The models produce dates in the form of posterior probability density functions—solutions to statements of Bayes' theorem (Bayes 1763) with calendar date information (usually calibrated ^{14}C dates) as the likelihood functions and relative date information as the prior probability functions. The relative dating information constrains the distribution of probable age estimates, thereby increasing precision. Common priors are statements that a set of ^{14}C dates should be from a single phase, or that a set of ^{14}C dates should occur before a known-age stratigraphic marker like a tephra layer. These statements are simple to express mathematically, but usually require Markov chain Monte Carlo (MCMC) methods to solve, which can be implemented in OxCal software (Bronk Ramsey 1995; Gilkes et al. 1995; Buck and Millard 2004). The models also detect outliers, or age estimates that are likely inaccurate based on all available information (Bronk Ramsey 2009b). This introduces objective mathematical justification for removing outliers, rather than relying on researchers to subjectively handpick dates that appear to be aberrant.

Chronologies based on Bayesian models of ^{14}C dates that have passed explicit selection criteria can alter our interpretations of the past. Bayesian modeling has revised chronologies in many regions and periods, including Paleolithic Europe (Bronk Ramsey 1995; Higham et al. 2012), Dynastic Egypt (Dee et al. 2009), and the Iron Age Levant (Boaretto et al. 2005), and the method is now gaining popularity in Latin American archaeology (Kennett et al. 2011, 2013; Marsh 2012; Ogburn 2012) (although see Zeidler et al. 1998 for an early application). Here, we present the first Bayesian modeling of a robust database of critically reviewed ^{14}C dates from Moche contexts.

METHODS

Sites, Sample Selection, and Bayesian Models

We combined absolute date measurements with other chronostratigraphic information in Bayesian models to define the length of ceramic phases at each site (Figure 2, Table 1). It was important to create independent models for each site, and then to combine the site-specific phases into a regional chronology. We cannot assume phases occurred synchronously at each site; this assumption is in fact what we intend to challenge through independent absolute dates.

We applied the following selection criteria to decide whether to include ^{14}C dates in our chronology. First, we only considered dates that the authors assigned to a specific ceramic phase based on association with diagnostic vessels. The ^{14}C samples belong to one of the Southern Moche I–V or the Northern Early, Middle, Late Moche phases. Additionally, Koons (2012) identified a new style of ceramics associated with the site of Licapa II in the Chicama Valley "heartland," which she called Licapa A. ^{14}C dates from nine Licapa A-associated samples are considered here for comparison with the other, better known, Moche styles. From the dates with ceramic associations at all sites, we selected measurements made on short-lived materials like annual plants and bone collagen. We removed samples with insufficient laboratory information or those measured very early in the history of ^{14}C dating. Lastly, we removed some statistical outliers with explicit justification, detailed below.

Unfortunately, the selection criteria left us with little to no ^{14}C dates for a number of sites. Therefore, two classes of modeled phases were created: secure phases were estimated by models that only include ^{14}C dates that passed the selection criteria. Uncertain phases include dates that failed to meet selection criteria. In most cases, the failure is due to charcoal samples that may bias phases older than reality (old-wood effect) or because the samples were measured early in the history of ^{14}C dating. We only included uncertain phases when there were insufficient reliable ^{14}C dates to estimate the span. These phases are included to indicate the presence a phase at a particular site, but are shown in dashed-faded boxes in Figure 2 to emphasize the uncertainty in absolute timespan.

The Appendix (online Supplemental file) shows the ^{14}C sample data used to construct the models. For each site, we describe the model and show both the included and excluded samples with accompanying ^{14}C BP age, material, modeled/calibrated date (cal AD), and context. Sample context and material are described as published in the excavators' own words, rather than standardized for our database. The purpose of this table is to provide researchers with sufficient sample information to independently evaluate the ^{14}C record and our models. An acknowledged shortcoming is the lack of information on sample pretreatment and preservation parameters. The availability of this information varied enormously between data sets, and we direct researchers to the original publications for more details.

Calibration and modeling was done with OxCal v 4.2 software (Bronk Ramsey 2009a) using the SHCal13 calibration curve (Hogg et al. 2013). The models applied priors of single or overlapping phases, as defined by Bronk Ramsey (2009a). By grouping ^{14}C dates in a phase, we have made the assumption that they are more likely to occur between some undefined start and end date, rather than any time. Our phases were defined by ^{14}C samples associated with diagnostic vessels of a particular ceramics phase. When more than one phase occurred at a given site, the phases were designated as overlapping—meaning we did not constrain the phases to a particular order, or require that one ended before another began. It is quite possible that one ceramic style gradually faded as another emerged, and thus overlapping phases is an appropriate model structure. The reported spans (Table 1, Figure 2) range from the earliest to latest modeled, calibrated date in each phase. Specifically, we report the beginning of the 68% highest probability density of the earliest date to the end of the 68% highest probability density of the latest date.

Outliers were determined by individual agreement indices (A_i), 100 times the ratio of the mean likelihoods of obtaining the date under the experimental model over that of the null model, which is in practical terms no model (Bronk Ramsey 1995). It is recommended that dates with $A_i < 60\%$ be considered outliers, although the exact cut-off is arbitrary and not determined by formal statistics. We used A_i values to flag potential outliers and tested the effect of removing or retaining them on model outputs. The agreement of models was evaluated by overall agreement indices (A_{model}). Again, $A_{model} < 60\%$ is the recommended threshold to indicate that the model structure or individual measurements within it are incorrect (Bronk Ramsey 2009a,b).

The dates that were used in this analysis come from 11 sites across the Southern and Northern Moche regions (Figure 1). In Figure 2, from left to right, these sites are shown from south to north. The southernmost site in this analysis is Guadalupito in the Santa Valley (Chapdelaine 2010). Of the six measured ^{14}C dates, only four were from secure Moche IV contexts, and these were combined in a one-phase secure model. Moving north, the second set of dates is from Huaca de la Cruz in the Viru Valley. Strong and Evans (1952) reported two dates in association with what they considered to be Moche IV ceramics. Although the measurements were made over 6 decades ago, we included them in a one-phase uncertain model because they are the only absolute dates available for this site, and are at least from short-lived textile and basketry.

Dates from two sites in the Moche Valley were considered in our analysis, Huacas de Moche and Galindo. We used 29/32 published dates from Huacas de Moche, one of the largest and best-known Moche sites (Chapdelaine 2001; Uceda et al. 2001, 2007). We combined samples from three areas of the site (Huaca de Luna, Uhle Platform, and the Urban Zone) into an uncertain model of two overlapping phases of Moche III and Moche IV materials. Unfortunately, nearly all of the samples were just described as charcoal, so it is unclear if the old-wood effect may be biasing age estimates older. Hence, the Huacas de Moche model is classified as uncertain.

Dates from Galindo were obtained by Lockard (2005, 2009). Out of 13 published dates, we used the seven short-lived samples from maize or reed in Moche V contexts to produce a secure one-phase model. The other dates were excluded because they came from unidentified charcoal.

Twenty-one dates from Moche I/II, III, and IV contexts have been reported for El Brujo in the Chicama Valley (Franco et al. 2003; Quilter et al. 2012; D Vargas, personal communication). However, there were only short-lived samples of known material from the Moche I/II and Moche IV contexts. The two samples from Moche III contexts were wood and unspecified charred material (Beta-230126, Beta-230123). Thus, we created two models. The secure model is two overlapping phases of the reliable dates from Moche I/II and Moche IV contexts. We removed one sample of unspecified plant material (Beta-109132) and one sample with $A_i < 60\%$ (OxA-7007). This model was used to estimate the phases of Moche I/II and IV at El Brujo. The uncertain model includes the Moche III dates, and comprises three overlapping phases of Moche I/II (reliable), Moche III (all), and Moche IV (reliable) dates. Our ranges for Moche I/II and IV can be thought of as secure, while the Moche III range certainly exaggerates the temporal span of this ceramic phase. Moche III at El Brujo most likely emerged during or near the end of the secure Moche I/II phase (cal AD 573) and went out of style near the beginning of the secure Moche IV phase (cal AD 601).

All of the published Cerro Mayal dates are from Moche IV contexts (Russell et al. 1998). Because the samples were from "charred wood" of unknown species, we created an uncertain one-phase model for this site. Some of the dates are replicate samples measured at different laboratories, Beta Analytic (Beta) and Desert Research Institute (DRI). The measured ^{14}C BP ages are not identical.

The Combine function in OxCal allows us to test if these differences are significant with a χ^2 test. The test showed that the ^{14}C BP yr were the same for one replicate pair (Beta-71085: 1280 ± 50 BP and DRI-2858: 1365 ± 46 BP), meaning that differences are due to chance or within analytical error. However, the other replicate pair (Beta-71081: 1320 ± 50 BP and DRI-2857: 1491 ± 52 BP) had significantly different ^{14}C BP measurements. In other words, the two laboratories measured different ^{14}C dates for the same sample. The Beta measurements are more consistent with other Moche IV dates from Cerro Mayal, but all of the other dates were also measured at Beta. For both replicate pairs, the DRI measurement is older than the corresponding Beta measurement. Likely explanations for this discrepancy (which is significant for one pair) are (1) modern carbon contamination in the seemingly younger measurements or (2) different portions of the same wood sample, which were formed at different times, were measured. Because it is unclear whether differences are due the nature of the sample or pretreatment procedures, we have no reason to trust one set of dates over another. Thus, we have combined dates of replicate samples in this model.

Koons (2012) measured 25 dates from Licapa A and Moche IV/V mixed contexts at the site of Licapa II in the Chicama Valley. We created a secure model of two overlapping phases of Moche IV/V dates and Licapa A dates. From the Moche IV/V phase, we used 6/14 reported dates, removing five wood samples and four samples from "sterile sand," a poor context that likely precedes the occurrence of Moche IV/V. From the Licapa A, we used 6/10 reported dates and removed those measured from wood. We also removed one sample without ceramics in clear association. Three of the samples from Licapa II were divided and sent to two laboratories: Beta Analytic and the AMS laboratory at the University of Arizona, Tucson (AA). One of the pairs, a corn sample (Beta-302519: 1470 ± 30 BP and AA-94819: 1572 ± 35 BP) failed the χ^2 test in the Combine function, indicating that the measurements are significantly different. Unlike the disagreeing dates from Cerro Mayal, in this case, the discrepancy must be due to differing pretreatment procedures because corn is an annual plant that should yield one age estimate, no matter how you cut it. Comparing all the replicates as well as samples that came from the same context but were measured in different laboratories, we see that the Beta measurements are always younger than the corresponding Arizona measurements (Figure 3). In many cases, systematically older dates have been trusted over younger dates when comparing two pretreatment techniques or analytical laboratories (Jacobi and Higham 2008; Talamo and Richards 2011; Higham et al. 2012). This is due to the ease with which modern carbon contamination can bias results younger if pretreatment procedures are insufficient (Boaretto et al. 2005; Higham 2011). Following this practice, we have chosen to use the Arizona measurements over the Beta measurements for replicate samples from the Koons (2012) sample set. However, we acknowledge that older does not necessarily mean more accurate and include both results in the data set. The differences raise concerns about the interlaboratory comparability of measurements from two of the most active AMS laboratories in the United States.

The Northern Moche ^{14}C dates come from two sites in the Jequetepeque Valley (Dos Cabezas and San José de Moro), one in the Lambayeque Valley (Pampa Grande), and one in the La Leche Valley (Pueblo Batán Grande). The five Dos Cabezas dates are from Early Moche contexts in two areas of the site (Donnan 2007). These dates seem reliable as they are from textiles and desiccated brain, and we combined them in a secure one-phase model. Four dates from San José de Moro were processed and reported in 2011 (Castillo 2011). Only one was from a short-lived sample, so we made an uncertain model of two overlapping phases of Late Moche and Early Transitional dates. For Pampa Grande, we made a secure one-phase model of reliable Moche V dates, using those reported by Shimada (1994). We removed one wood sample from Shimada's reported dates. Lastly, the three published charcoal dates from Pueblo Batán Grande were included in an uncertain model of two overlapping phases of Moche IV and Moche V materials (Shimada 1994).

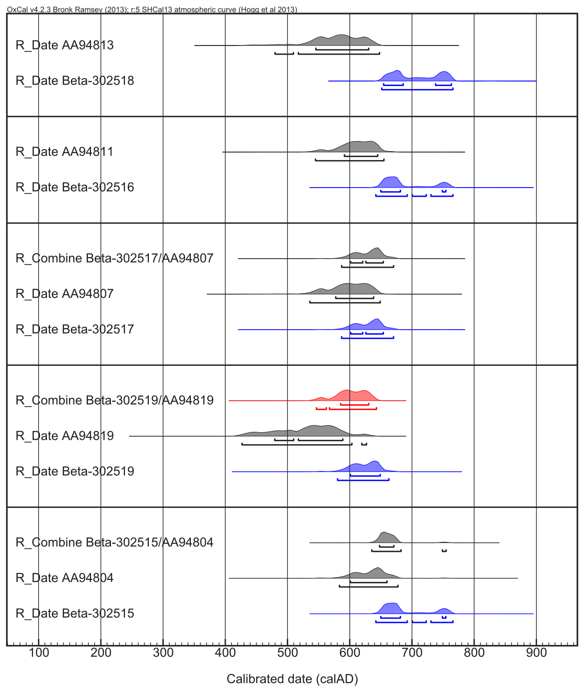

Figure 3 Samples from Licapa II sent for interlaboratory comparison to Beta Analytic (Beta, blue) and the AMS laboratory at the University of Arizona, Tucson (AA, black). Estimates show the 68% (upper bracket) and 95% (lower bracket) highest probability density estimate for ^{14}C dates calibrated with the SHCal13 (Hogg et al. 2013) in OxCal v 4.2 (Bronk Rasmsey 2009a). The upper two comparisons are samples from the same context, while the lower three are replicates, or individual samples divided and sent to separate laboratories. R_Combine shows the estimated combined date. A corn sample (Beta-302519, AA-94819) failed to combine (red), meaning the replicate yielded significantly different ^{14}C measurements at the different laboratories according to a χ^2 test.

RESULTS AND DISCUSSION

Ceramics and Chronology

All the dates used to construct secure models in this analysis are from short-lived organic materials associated with ceramics of different identified Moche phases/styles. The dates represent the time of deposition of the ceramic and not necessarily the time when the ceramic was manufactured or used. We note that burial contexts could include heirloom ceramics that were curated before and during the lifetime of the individual interred. Ceramics could have had a short use life or, in the case of some fine wares, a multigenerational one. Although it can be argued that chronological problems can arise from dating the context of discarded sherds, we believe that when all the dates are considered together meaningful results can be inferred. Although ^{14}C dating has greatly improved in precision and accuracy, the error range for this time period in the Southern Hemisphere can still encompass up to 150 yr, or five human generations. With this being the case, we believe that the probability of the time of sherd discard (within five generations of manufacture) likely fell within the range of error of the ^{14}C date of the associated material. Therefore, we feel it appropriate to use our results as a revised general framework for Moche chronology.

Although dates are not available from all Moche sites and contexts, we think that the sample here is an appropriate representation of Moche archaeology, as it is known today. As more reliable, well-contextualized dates are acquired, the models can be updated. Nonetheless, in Figure 2 we can clearly see that the original ceramic phases (Larco's 1948 Southern and Castillo and Donnan's 1994 Northern sequences) do not match our proposed absolute chronology established by modeled, calibrated ^{14}C dates.

Prior to this analysis, Moche I/II was thought to come before Moche III. However, the earliest dates come from Moche III contexts at the Huacas de Moche (cal AD 147–644). Since this is the largest and purportedly most influential Moche site, these early dates are not unreasonable. The Moche I/II contexts date later and are from El Brujo in the Chicama Valley[3] (cal AD 345–573). It is important to reiterate that Larco based his sequence on relative dating techniques in the Chicama Valley. Even though our sample of Moche III dates from El Brujo look as though they predate the Moche I/II contexts from this site, it is important to note that there are only two Moche III dates from El Brujo (cal AD 255–682) and they are not reliable materials. Therefore, it is possible that Moche I/II does still predate Moche III in the Chicama Valley, but more secure dates are needed to confirm if this is true. Nonetheless, the fact that the earliest Moche III predates Moche I/II at Huacas de Moche and perhaps El Brujo indicates that there are indeed problems with the entire Larco sequence and not just between Moche IV and V as has already been discussed (Lockard 2009). Because of these discrepancies, we suggest that Moche III was a style local to the Moche Valley that was later adopted in the Chicama Valley. The data also suggest that Moche I/II was a local Chicama style that may have had stylistic influences on the Early Moche style (or vice versa) seen to the north and at sites such as Dos Cabezas (cal AD 458–589). The Licapa A style (cal AD 599–672) is also a local style adopted in the northern Chicama Valley while Moche III may still have been in use at El Brujo. The Licapa A style does show some Moche III influence, but is a distinct and unique style (see Koons 2012:255–7). Overall, prior to cal AD 600–650, Moche people living in the various valleys seem to have been using regional ceramic styles.

The gray horizontal band between cal AD 600 and 650 in Figure 2 marks a time when many changes occurred in the Moche world. This includes the abandonment of sites and initial occupation of others, changes in architectural layout and type of structures, and an overall shift in ceramic styles (Shimada 1994; Bawden 1996; Koons 2012). The date cal AD 600 corresponds to the purported closing of the Huaca de la Luna and excavations have shown that Moche IV ceramics were only adopted for the final phase of its use (Uceda 2010). Our analysis agrees with this argument and suggests that about a century prior to cal AD 600, Moche IV ceramics were developed in the Moche Valley at the Huacas de Moche (cal AD 508–731). It is around cal AD 600 when Moche IV ceramics are introduced at El Brujo (cal AD 601–760) and the final huaca is constructed to mirror the Huaca de la Luna (Mujica 2007). At this time, sites such as Dos Cabezas were abandoned and other sites, such as Guadalupito (cal AD 660–762) and Cerro Mayal (cal AD 630–849), first were occupied. Moche IV and IV-like contexts characterize these post-cal AD 600 sites. We say Moche IV-like because the Moche IV style in the Santa Valley is actually not the same as the Moche IV style in the Chicama and Moche Valleys, as discussed above. It should also be noted that the Moche IV dates from Huaca del Pueblo Batán Grande (cal AD 520–641) appear to be earlier than the Moche IV dates in the south. These dates are uncertain, and may reflect the old-wood effect because the samples are unspecified charcoal. There is also very little published information on the nature of the Moche occupation at this site (cf. Shimada 1994), so the context is not fully understood. Therefore, the timespans suggested at Pueblo Batán Grande should not be given much weight or authority in our reconstruction of overall Moche dynamics.

Around the time Moche IV is introduced on the coast of Peru, a whole host of other changes began to occur. At Licapa II, Moche IV and V are adopted by cal AD 650 (cal AD 652–813). In fact, Licapa II has the earliest occurrence of Moche V wares and elsewhere Koons (2012) suggests that this style was invented in the northern Chicama Valley. Site such as Galindo (cal AD 673–764) and Pampa Grande (cal AD 663–805), both containing Moche V ceramics, also are first occupied post-cal AD 650. Other sites, such as Cerro Mayal and Huacas de Moche, continue to be occupied but

3. The overwhelming majority of all Moche I/II vessels are from the Chicama Valley. There is little evidence for Moche I/II in the Moche Valley. In 1899, Max Uhle found one Moche I/II burial and three Moche II burials at the Huaca de la Luna (Kroeber 1925) and Theresa Topic (1982) excavated one Moche I burial 6 m below the surface at the base of the Huaca de la Luna. Neither of these contexts was dated. There is no evidence for this phase farther to the south.

also continue to use and produce Moche IV ceramics. Late Moche ceramics are adopted at San José de Moro also post-cal AD 650 (cal AD 764–890).

The initial spread of Moche IV seems to have reconfigured north coast ideology around cal AD 600 and many groups and settlements adopted aspects of the Moche IV ideology. However, the Moche IV phenomenon was quickly reinterpreted in the varying locales and out from it emerged the Moche V, Late Moche, and possibly other localized styles beginning around cal AD 650.

It is also seems that time is more significant than space in terms of shared ideology; thus, our idea of the Northern and Southern Moche should be reevaluated. Of the four Northern Moche sites studied, two are characterized by Southern Moche ceramics. Other Northern sites without published ^{14}C dates, such as Pacatnamú and Huaca Colorada, also have Southern Moche V ceramics (Ubbelohde-Doering 1983; Swenson and Warner 2012). Therefore, rather than accept that Moche was characterized by a northern and southern sphere, this analysis suggests that each valley, or region, used its own local style of ceramics that was within the understood framework of an overall aesthetic tradition. Where aberrations are seen in this pattern, such as Moche V ceramics at Pampa Grande and other Northern sites, suggests that people were in communication and affiliated through marriage, kin, politics, religion, or other means. The patterns do not suggest overt state control or conquest, but rather demonstrate that the political landscape was complex and changed through time.

If we accept that Moche ceramics are regional styles, rather than temporal phases, and that the south had just as many regional variants as the north, then the geographic distributional pattern of where and when ceramic styles are found has profound implications for our understanding of political dynamics and affiliations between sites through time. Considering this, a crucial question is what happened around cal AD 600–650 that caused such widespread changes in the ceramic styles throughout the entire Moche world.

Changes between AD 600–650

The reorganization of the Moche ideological world has been noted before, but without reliable radiometric dates, the order of events was understood differently. Bawden (1996) and others (Moseley and Deeds 1982; Shimada 1994; Dillehay and Kolata 2004; Moseley et al. 2008) proposed that drought and El Niño, which destroyed houses, fields, irrigations systems and temples, caused social and economic disturbances between Moche IV and V (originally thought to be around AD 550–600). These researchers proposed that these climatic events led the Moche people to ultimately lose faith in their gods and rulers, who were the mediators, or even god-impersonators, and were supposed to protect them. The ruling class was forced to make political and ideological changes to regain the support of the people. Bawden (1996) and Shimada (1994) suggested that this reorganization led to the abandonment of Huacas de Moche and the establishment of Galindo and Pampa Grande. The Moche IV style was rejected for the Moche V, which was thought to demonstrate the ideological shift in organization. From ^{14}C dating and refinement of the ceramic sequence, we now see that the relationship between Moche IV and V was more complicated. Likewise, the relationship between people at Galindo, Pampa Grande, and Huacas de Moche was also likely much more complex than had been originally proposed. Nonetheless, there was marked change in organization in the Moche world sometime around cal AD 600. How and if this relates to climate change and/or other political and religious factors, such as highland influences by the Wari and/or other groups, such as the Recuay (see Lau 2002, 2004), will need to be addressed in light of our new understanding of ^{14}C dates and ceramic style.

Span of Moche

Finally, it has long been suggested that the Moche archaeological culture dated from AD 1–800. However, reviewing the published dates indicates that there is little evidence for this claim and the span of Moche should be revised to cal AD 200–900 or less. The earliest properly reported Moche dates come from the Huacas de Moche, but these dates are from charred wood that may radiometrically predate its archaeological use. Short-lived ^{14}C samples from the lowest Moche levels of the site should be obtained to better date the emergence of Moche wares and ways.

More dates exist from the end of Moche, and all cluster around cal AD 850–900, or 50–100 yr later than previous estimations. The transition from what we understand to be Moche material culture to Transitional period and Lambayeque material culture is most apparent at San José de Moro. At most other Moche sites, the transition to post-Moche is unclear and likely took place at different rates in different regions. More dates from early Moche and Transitional contexts would refine the chronology.

CONCLUSION

This study has added to the growing efforts to establish best practices for reviewing and utilizing published ^{14}C records to revise archaeological chronologies. The discrepancies observed here between replicate samples measured at different laboratories should raise concerns about interlaboratory comparability. We stress that these discrepancies can only be resolved and ^{14}C dates can only be deemed reliable if the measurements are accompanied by sufficient information on the samples' archaeological contexts, material properties, and analytical procedures.

Our evaluation of the Moche ^{14}C record demonstrates that ceramic phases are insufficient for understanding Moche chronology. However, by careful analysis of the absolute dates associated with ceramic styles at different sites, we can begin to reconstruct Moche political dynamics and site affiliations. Absolute dates suggest the Moche civilization spanned between cal AD 200–900, which is different from the formerly accepted AD 1–800. Before cal AD 600, sites utilized local styles that do not correspond to a temporally synchronous regional sequence of ceramic phases. Likely reflecting widespread political and social changes, between cal AD 600–650, Moche IV, V, and Late Moche are adopted at roughly the same time at different sites throughout the Moche world and suggest that political affiliation were more complex and extended beyond local spheres in this later Moche phase. This analysis shows where the different styles (phases) likely originated and how and when they spread to other sites and regions. It is a major step towards deconstructing the notion of the homogenous Moche state and reconstructing Moche political organization with nuanced complexity.

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