Spatiotemporal diversification of projectile point types in western North America over 13,000 years

Marcus J. Hamilton[a,b,*], Briggs Buchanan[c], Robert S. Walker[d]

[a] Department of Anthropology, University of Texas at San Antonio, San Antonio, TX, United States of America
[b] Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, NM, United States of America
[c] Department of Anthropology, University of Tulsa, Tulsa, OK, United States of America
[d] Department of Anthropology, University of Missouri, Columbia, MO, United States of America

A B S T R A C T

North America was initially colonized by humans during the late Pleistocene, and over the course of the Holocene material culture diversified as local populations adapted to regional environments. However, to date, while anthropologists and archaeologists have long been interested in diversity, little is known of the process of diversification over space and time. Here, we focus on the diversification of the archaeological record of western North America over 13,000 years. By compiling time series of projectile point types and their spatial distribution, we quantify the empirical record of diversification in this region. Our results show that projectile point diversity increases exponentially over time, consistent with a simple evolutionary branching process. The spatial extent of projectile points decreases exponentially over time at a similar rate. Therefore, the evolutionary diversification of projectile point types in western North America is a fractal-like space-filling process, likely reflecting increasingly localized adaptations to regional environments and a consequent reduction in the spatial extent of cultural networks.

1. Introduction

Understanding diversity and diversification lies at the heart of evolutionary approaches to science. Mathematically, diversification is best modeled as an evolutionary branching process (Karlin, 2014; Kimmel and Axelrod, 2016) where ancestral forms diverge over time in response to the interaction of internal dynamics and external stimuli resulting in the origination of descendent forms, be they biological species or human cultural traits (Henrich and McElreath, 2003; Maffi, 2005; Nettle, 1999; Nunn, 2011). As the human species expanded its range out of Africa, human socioeconomies diversified as populations encountered and adapted to new environments (Hiscock, 2013). Coupled with global-scale climate changes at the end of the Pleistocene, regional technological adaptations led to the modification of ecosystems (i.e., niche construction) that created coevolutionary feedbacks between human populations, their technologies and their environments. In several places around the planet these coevolutionary feedback loops resulted in the increased management and the eventual domestication of plants and animals (Bellwood, 2005). As a result, human cultures, socioeconomies, and social complexity diversified worldwide over time as local adaptations, and their diffusion (Bailey

et al., 2012; Bellwood and Renfrew, 2002; Diamond and Bellwood, 2003), led to novel technological, economic, and cultural innovations creating spatiotemporal patterning in the archaeological record.

Social scientists have long been interested in quantifying human cultural diversity. Since the mid-1990s anthropologists have sought to understand the global biogeographic structure of linguistic diversity (Axelsen and Manrubia, 2014; Cashdan, 2001; Collard and Foley, 2002; Currie and Mace, 2012; Gavin et al., 2013; Mace and Pagel, 1995; Maffi, 2005; Nettle, 1999). Similar research has explored ethnic (Ahlerup and Olsson, 2012; Burnside et al., 2012; Cashdan, 2001; Michalopoulos, 2012; Pagel and Mace, 2004), economic (Kummu and Varis, 2011), sociopolitical (Currie and Mace, 2009; Turchin et al., 2018), and mythological diversity (Berezkin, 2005, 2009). Phylogenetic approaches are commonly employed to reconstruct the evolutionary diversification of languages (Atkinson, 2011; Bouckaert et al., 2012; Gray and Atkinson, 2003; Greenhill et al., 2010; Grollemund et al., 2015; Pagel et al., 2007), sociopolitical complexity (Currie et al., 2010, 2013; Walker and Hamilton, 2011), mythologies (d'Huy, 2013a, 2013b, 2013c) and folktales (Da Silva and Tehrani, 2016; Pagel, 2016; Tehrani, 2013).

Others have measured the pace of cultural evolution using

* Corresponding author at: Department of Anthropology, University of Texas at San Antonio, San Antonio, TX, United States of America.
  E-mail address: marcus.hamilton@utsa.edu (M.J. Hamilton).

archaeological data by quantifying rates of change in artifact form over time (Perreault, 2012). Researchers studying the evolutionary diversification of stone tool technologies, for example, often use morphometric cladistic approaches to measure rates of change in continuous measures of shape, as opposed to the discrete traits required by phylogenetics (Buchanan, 2006; Buchanan et al., 2011; Buchanan and Collard, 2010a, 2010b; Buchanan and Hamilton, 2009; Costa, 2010; Eren and Lycett, 2012; Iovita, 2011; Iovita and McPherron, 2011; Lyman et al., 2008, 2009; Lyman and O'Brien, 2000; Mesoudi and O'Brien, 2008a, 2008b; O'Brien et al., 2001, 2002; Thulman, 2012). The resulting evolutionary structure gives insight into the processes of innovation, selection, and drift in the diversification process. Approaches that explicitly consider the spatiotemporal diffusion of technologies and populations use geolocated radiocarbon databases. Here, population expansions, or the diffusion of innovations, are traced through spatiotemporal gradients in the radiocarbon record (Cavalli-Sforza et al., 1993; Collard et al., 2010; Fort, 2012; Fort et al., 2004; Hamilton and Buchanan, 2007, 2010; Pinhasi et al., 2005).

In this paper, we focus on the diversification of stone tool technologies in North America from the initial colonization by humans in the late Pleistocene through the Holocene. Specifically, we examine the spatiotemporal diversification of projectile point types in western North America over a period of about 13,000 years. While the specific timing and nature of the initial colonization of the Americas is an area of active debate (Braje et al., 2017, 2018; Potter et al., 2017, 2018), most experts agree that late Paleolithic hunter-gatherer populations from northeast Asia entered North America via the Bering Land Bridge, first appearing in western Alaska sometime during the late Pleistocene (Hamilton and Buchanan, 2010; Madsen, 2004; Meltzer, 2009). A small founding population later entered the North American continent south of the ice sheets and rapidly expanded across the continent (Hamilton and Buchanan, 2007). Both the genetic and archaeological records show that this small founding population exhibited low levels of diversity. However, recent research shows that early Paleoindian populations had already diversified into distinct, spatially discrete regional variants across North America by ~12,000 cal BP (Buchanan et al., 2016a). Moreover, this diversification suggests an adaptive radiation as regional variation in stone tool technologies and projectile point shapes correlate with regional variation in the body size spectrum of major mammalian prey species (Buchanan et al., 2011).

We chose western North America as our study region as there are various data sets available with which to study diversification over time. First, we summarize the available data. Second, we analyze projectile point type diversification over time. Third, we analyze projectile point type diversification over space. Fourth, we then consider the spatiotemporal dynamics in relation to population growth and regional climate changes over the study period. We also address potential sampling bias in the identification of projectile point types over different time periods.

2. Results

2.1. Data

2.1.1. Projectile point types

We extracted data from Justice's projectile point typologies of the US Southwest (Justice, 2002a), and California and the Great Basin (Justice, 2002b). For each projectile point type, we recorded maximum date (origination) and minimum date (extinction) (Fig. 1), and calibrated them using the calpal Intcal 13 calibration curve (Danzeglocke, 2018). We then digitized the projectile point distribution maps for each type (where available) built shape files of their spatial distribution and measured the areas in a GIS (Fig. 2). The database is available in the Supplementary Material. Fig. 3A shows the probability distribution of projectile point types in 1000-year bins.

2.1.2. Relative population size estimates

We used the CARD database (Gajewski et al., 2011) to generate a proxy timeseries of relative population sizes using radiocarbon dates from the region covered by the Justice data. This included data from Arizona, New Mexico, California, Idaho, Colorado, Utah, Nevada, and Oregon (Fig. 3B). From the CARD data we used only those dates from archaeological contexts, ($n = 17,360$). These dates were then calibrated using the calpal Intcal 13 curve (Danzeglocke, 2018). We then created the time series by binning the total number of dates in 1000-year increments (Fig. 4A, blue data points). We employed a simple taphonomic correction to these data, based on a method described by Surovell and colleagues (Surovell et al., 2009; Surovell and Brantingham, 2007). We fitted an exponential decay model to the Bryson et al. database (Bryson et al., 2006) of dated volcanic eruptions over the last 14,000 years. The model has the form $y(t) = ce^{-\beta t}$ and provides a good fit to the data (regression: $r^2 = 0.96$, $\beta_1 = 0.16$, $p < 0.0001$, Fig. 4B). We adjust the CARD relative population estimates by multiplying the binned data through by the taphonomic decay curve (Fig. 4A, black data points).

2.2. Projectile point type diversity through time

Fig. 5A shows the cumulative origination rate of projectile point types over time. In effect, this measures the accumulation rate, or appearance of new projectile point types in the archaeological record. The rate of increase is well-fit by an exponential function, indicating a constant growth rate of 28% per millennia ($2.8 \times 10^{-4} \text{yr}^{-1}$), or new projectile point types appear every 343 years over the 13,000 years in our sample window. Fig. 5B show the cumulative extinction of projectile point types, marking the rate at which projectile point types are no longer manufactured after their initial appearance. Similarly, this extinction process is also well-fit by an exponential function, indicating that extinction rates are 30% every millennium ($3.0 \times 10^{-4} \text{yr}^{-1}$). The diversity of projectile points, $D(t)$ used at any one time is $D(t) = S(t) - E(t-1)$; the net difference between cumulative origination and extinction rates. Fig. 5C shows the time series of projectile point type diversity is also well-fit by an exponential function with a diversification rate of 24% each millennium ($2.4 \times 10^{-4} \text{yr}^{-1}$), such that the evolution of projectile point type diversity over time is a constant branching process resulting from constant -and similar- rates of origination and extinction.

2.3. Projectile point type longevity

Fig. 6 shows that projectile point type longevity varies over time, first increasing, then decreasing. To estimate rates of change and the inflection point we fit a piecewise regression model to the logged data (2 segment piecewise regression: $r^2 = 0.79$, $p < 0.0001$). Results show that projectile point type longevity increases slowly over the first 10,000 years at a rate of about 8% per millennia, peaking at 3216 BP (2839–3683 BP, 95% C.I.) and then decreasing rapidly over the late Holocene at a rate of about 80% per millennia.

2.4. Projectile point type diversity in space

Fig. 7A shows that the spatial extent of projectile point types decreases exponentially toward the present at a rate of 30% per millennium ($3.0 \times 10^{-4} \text{yr}^{-1}$), similar to the rate at which projectile point type diversity increases with time (Fig. 5C). Fig. 7B shows a slight positive relationship between area and longevity, but the slope is not statistically different from 0, and the amount of variation explained is low ($r^2 = 0.04$). Therefore, the spatial extent of projectile point types is independent of longevity.

Because diversity increases at a similar exponential rate to the rate at which spatial extent decreases, projectile point diversification is a space-filling process, where each new projectile point type occupies a constant fraction of the area of its ancestral type (Fig. 8).
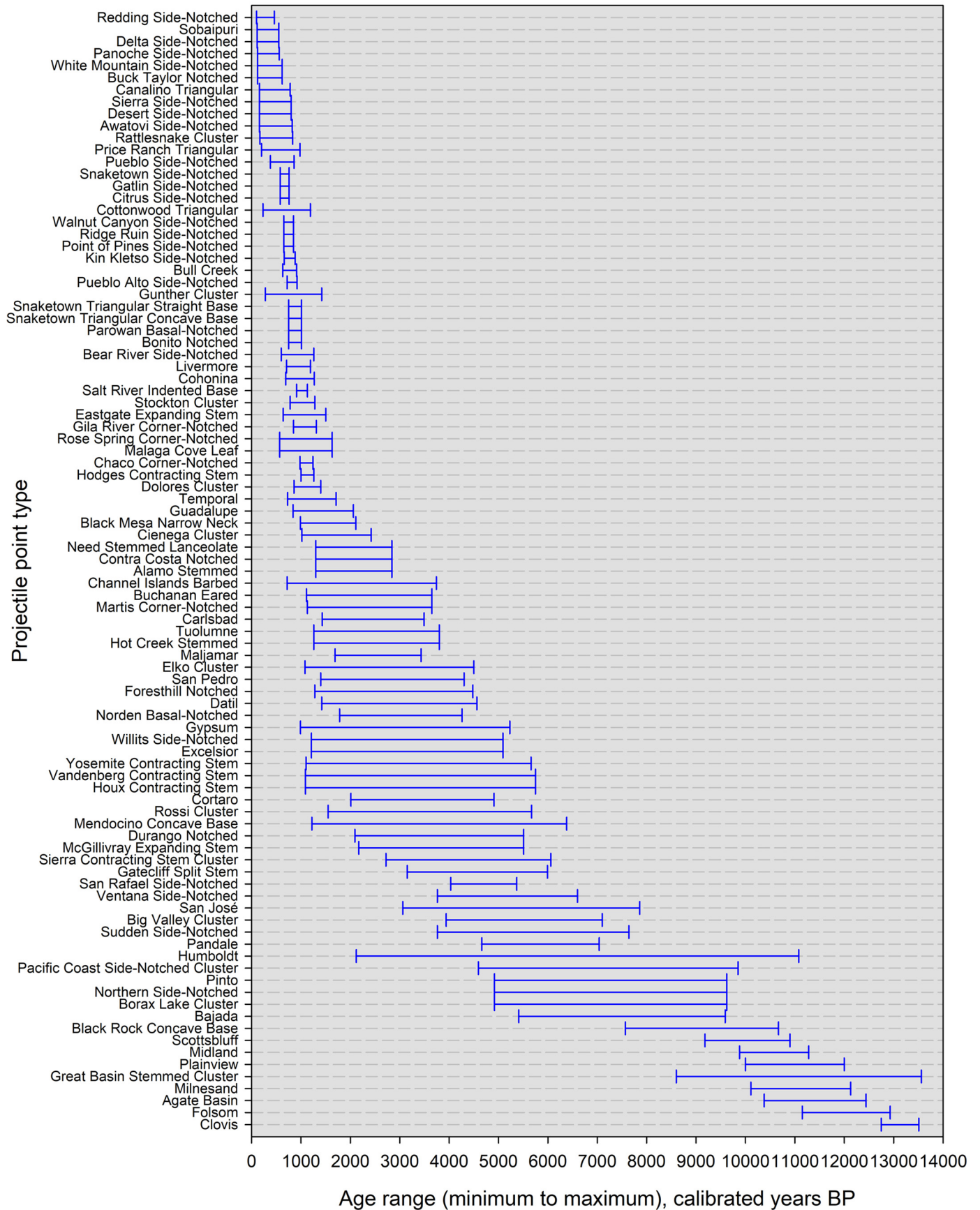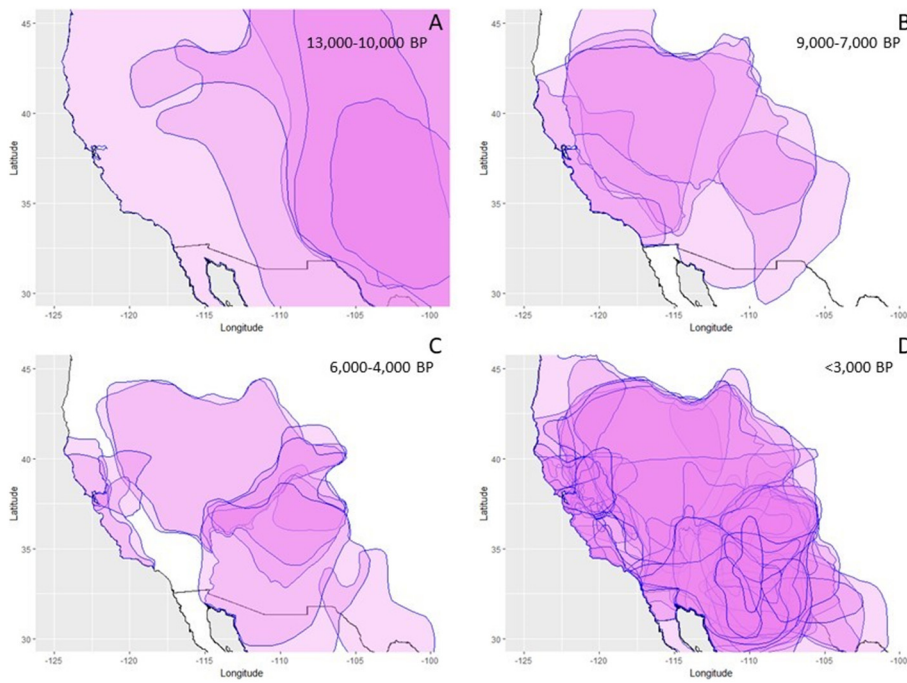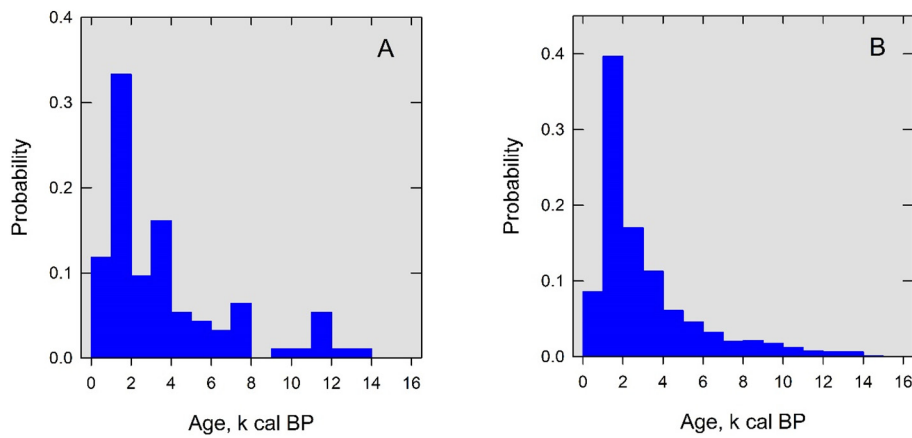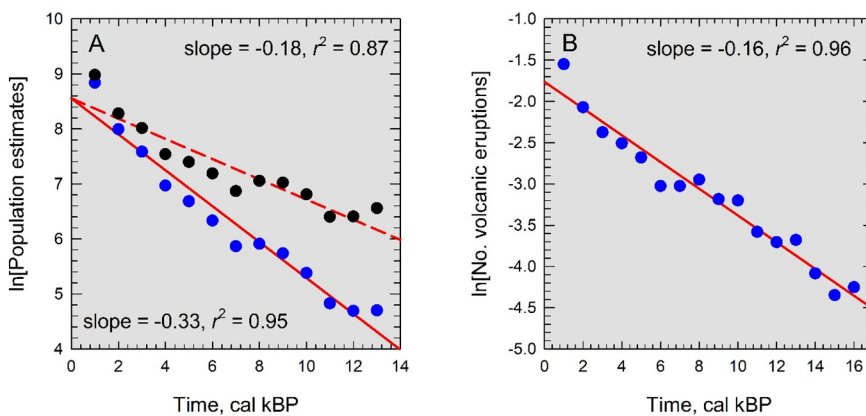
Fig. 1. The calibrated age ranges of western North American projectile point types used in this paper (*n* = 93), sorted top to bottom by average calibrated age.

Fig. 2. Maps of the spatial extent of projectile point type shape files in the study region over time. Pink polygons are the distributions of individual point types. A) 13,000–10,000 BP; B) 9000–7000 BP; C) 6000–4000 BP; D) < 3000 BP. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 3. Probability distributions of projectile point type diversity (A) and CARD estimates (B) over time. A Mann-Whitney test shows no significant difference between the two distributions (Mann-Whitney: $P = 0.346$).

Fig. 4. Relative population size and taphonomic correction curve over time. A) Blue data points are raw CARD data estimates, and the black data points are the taphonomically-corrected relative population size estimates. B) The taphonomic correction curve (the number of dated volcanic events over time) modeled as an exponential decay process. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.5. Relative population size

Using the taphonomically-corrected radiocarbon record as an indirect measure of relative population size through time, a regression fit estimates an exponential growth rate of 18% per thousand years, or an annual growth rate of 0.0018%. This slow growth rate suggests that human populations were near carrying capacity (i.e., $dN/dt = 0$) over most of human prehistory in the region (see Hamilton and Walker,
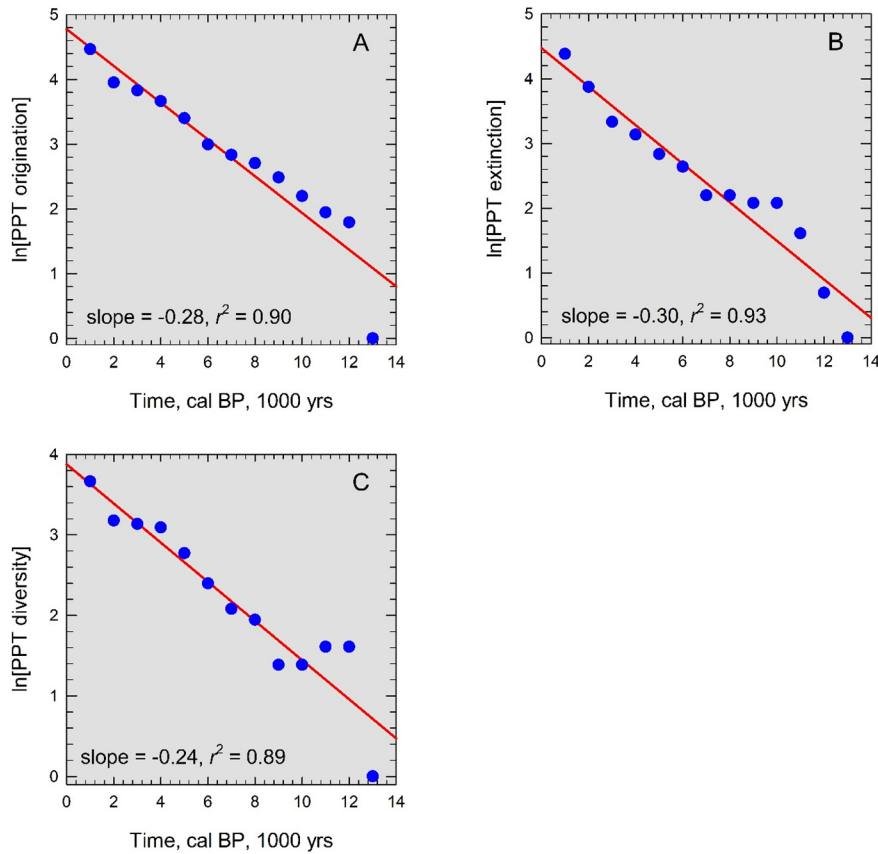
Fig. 5. Origination, extinction, and diversity of projectile point types through time. A) Cumulative origination of projectile point types over time. B) Cumulative extinction of projectile point types over time. C) Net diversity of projectile point types over time (i.e., diversity(t) = origination(t) – extinction(t-1)).
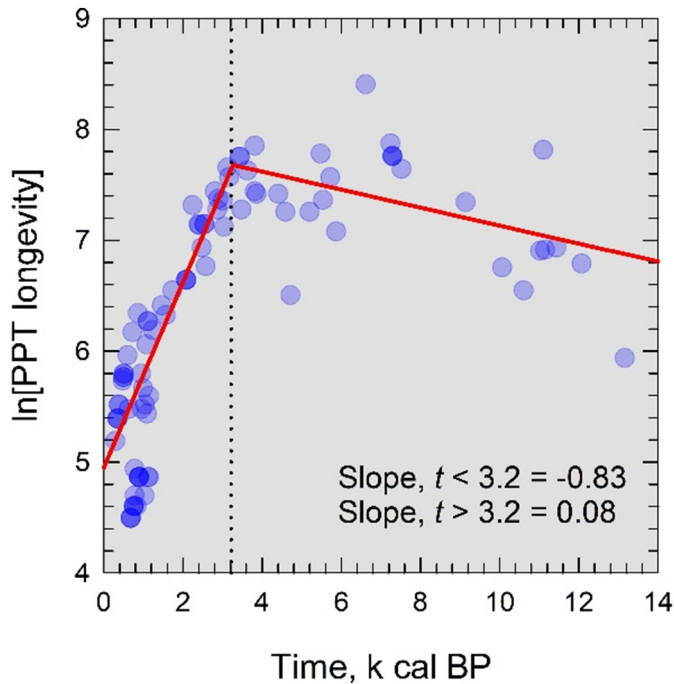

Fig. 6. Projectile point type longevity through time. The red line is 2-segment piecewise regression model ($r^2 = 0.79$, $t_{crit} = 3.216$(dotted line)). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2018).

Fig. 9A shows that projectile point type longevity, L, decreases with population size, N, as $L(N) \propto N^{-0.45}$. This means that the projectile point type replacement rate, $1/L$, increases with population size $R(N) \propto N^{-0.55}$. Therefore, the turnover of projectile point types through time increases with population size. Similarly, Fig. 9B shows that projectile point type, diversity D, increases with population size as $D(L) \propto N^{1.16}$, a superlinear rate. Therefore, both projectile point type turnover and diversity increase through time as functions of population size, though diversity increases at twice the rate of turnover.

2.5.1. Paleoclimates

We used average July temperature estimates derived from pollen counts reported in Viau et al. (2006). Viau et al. provide temperature records for six regions of North America in 100-year increments over 14,000 years using calibrated dates. We used the southwest record and took average temperatures by binning the data into 1000-year increments. Fig. 10A shows the time series of reconstructed average July temperatures over 14,000 years. Initially, temperatures drop precipitously over the late Pleistocene until ~11,000 BP, thereafter increasing linearly toward the present. We average the temperature data across 1000-year bins and plot them with population size in Fig. 10B, and diversity in Fig. 10C. Fig. 10B shows that while population size increases with temperature over time, the relationship is not statistically significant at the 0.05% confidence level. Similarly, Fig. 10C shows that projectile point type diversity also increases with temperature through time, but at a non-significant rate. However, if we exclude the outlier along the x-axis (which is the earliest data point, 14,000 cal BP), the relationship between diversity and temperature becomes highly significant (Fig. 9C, dashed line), showing $D(T) = ce^{0.48T}$.
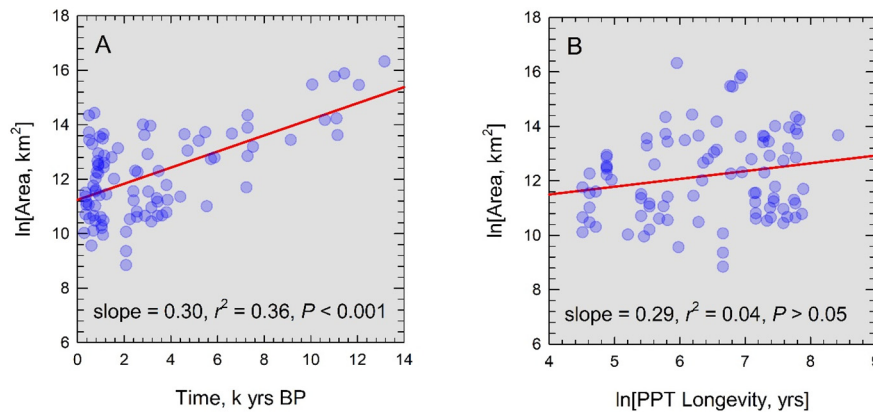
Fig. 7. Spatial extent of projectile point types. A) Spatial extent as a function of the initial appearance; and B) Spatial extent as a function of projectile point type longevity.
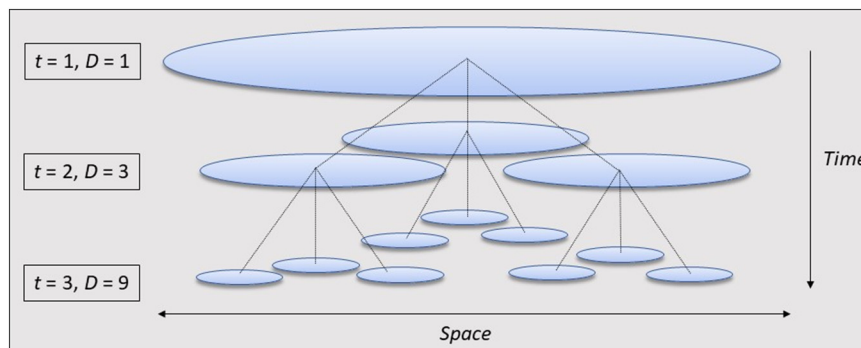

Fig. 8. A graphic of the spatiotemporal diversification process described by our results: t = time and D = diversity.
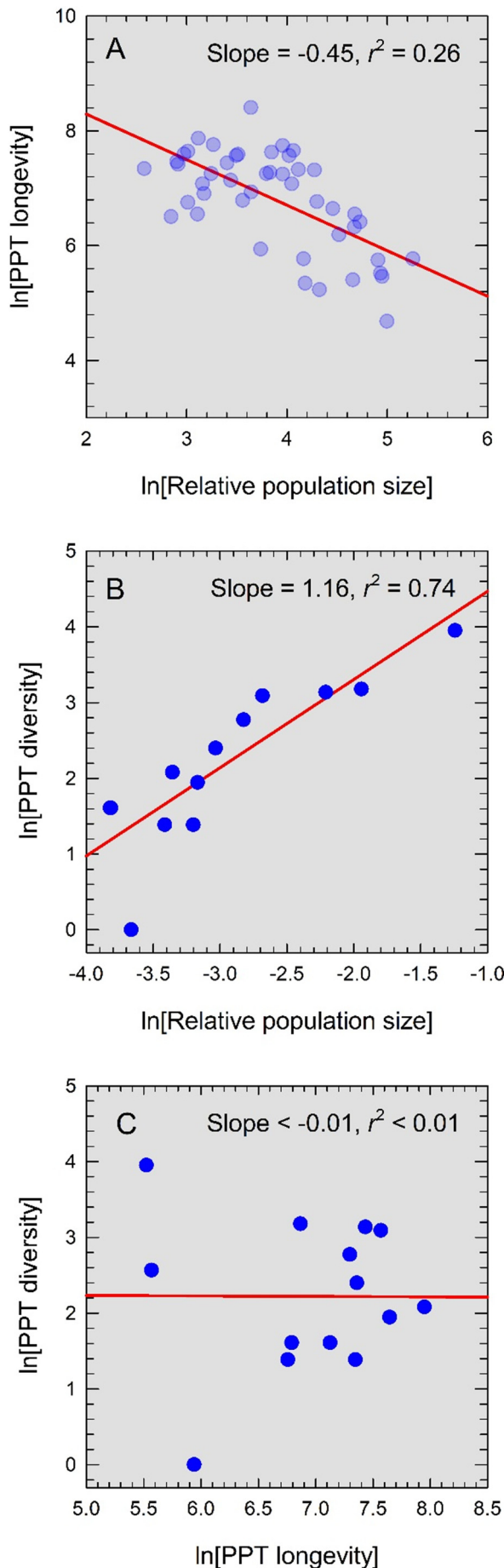
3. Discussion

Our results describe a complex diversification process where, following the initial human colonization of North America and expansion throughout western North America over the late Pleistocene, as temperatures increased over the Holocene, populations grew, innovated, and subdivided into increasingly localized subpopulations. Projectile point diversity consequently increased in proportion to population size, as did the replacement rates of projectile point types.

Cultural diversification of any kind is a 2-dimensional evolutionary process occurring simultaneously in time and space. The results we provide here give insights into how this spatiotemporal diversification process works in material culture. Our results show that projectile point type diversity increases exponentially over time consistent with a evolutionary branching process. Moreover, the spatial extent of projectile point types decreases exponentially over time. Because diversity increases with time as, as $D(t) = ce^{\alpha t}$, and area decreases with time as $A(t) = ce^{-\beta t}$, we can rearrange to express spatial extent, A, as a function of diversity D, yielding $A(D) \propto D^{-\gamma}$, $\gamma = \alpha/\beta = 1.25$. Therefore, the evolutionary diversification of projectile point types is a space-filling, branching process described by a power law with an exponent of -1.25. As the human population grew in size and expanded in space, subpopulations diversified into increasingly localized regional subgroups at a constant rate, likely reflecting increasingly specific adaptations to local landscapes and resources.

The evolution of projectile point type longevity over time is particularly interesting. Fig. 6 shows that projectile point type longevity increases at a slow but exponential rate for about the first 10,000 years of prehistory in the region, until ~3200 BP. After this inflection point, longevities begin to decrease rapidly toward the present. There are several ways of interpreting this pattern. If projectile point type longevity reflects the strength of stabilizing selection on projectile point

form, then stabilizing selection increases exponentially (albeit slowly) for the first 10,000 years of prehistory in western North America. If so, this suggests that each new type was an increasingly successful solution finely engineered to meet its specific technological role, resulting in a slow but steady increase in longevity over time. As such, under this scenario, innovations are adaptive solutions. The reversal in longevity after ~3200 cal BP would then imply that in the later Archaic projectile point longevity is no longer under stabilizing selection and projectile point forms are replaced at an increasingly frequent rate. If so, this might suggest a greater emphasis on trial-and-error learning. An alternative interpretation is suggested by Fig. 9A where projectile point longevities decrease with population size (or the inverse; replacement rates increase with population size). Under this scenario the reversal of projectile point longevities around 3200 cal BP is a function of a change in population growth rate at this time. Indeed, Fig. 4A seems to show increasing population growth toward the present.

Interestingly, the inflection point also coincides with the end of complex global-level climate changes in the mid-Holocene (Bond et al., 1997; Marsicek et al., 2018; Rehfeld et al., 2018; Steig, 1999; Viau et al., 2006; Wanner et al., 2008). During this period, most of western North America experienced extensive hyper-aridity (Dean et al., 1996), though increased monsoonal activity may have led to greater-than-present levels of precipitation in the Southwest (Harrison et al., 2003), with climates approaching present day-like conditions by the late Holocene (Holliday, 1997; Polyak and Asmerom, 2001). The archaeological record suggests these changing climatic conditions may have led to widespread population movements throughout western North America (Kennett et al., 2007) coinciding with the adoption of agriculture in the Southwest (Polyak and Asmerom, 2001). As such, decreased projectile point type longevities may reflect widespread population movements and/or novel technological innovations in response to new climatic conditions experienced by populations throughout the

Fig. 9. Projectile point type diversity, longevity (in years), and population size. A) Projectile point longevity as a function of population size. B) Projectile point type diversity as a function of population size. C) Projectile point diversity and projectile point type longevity.
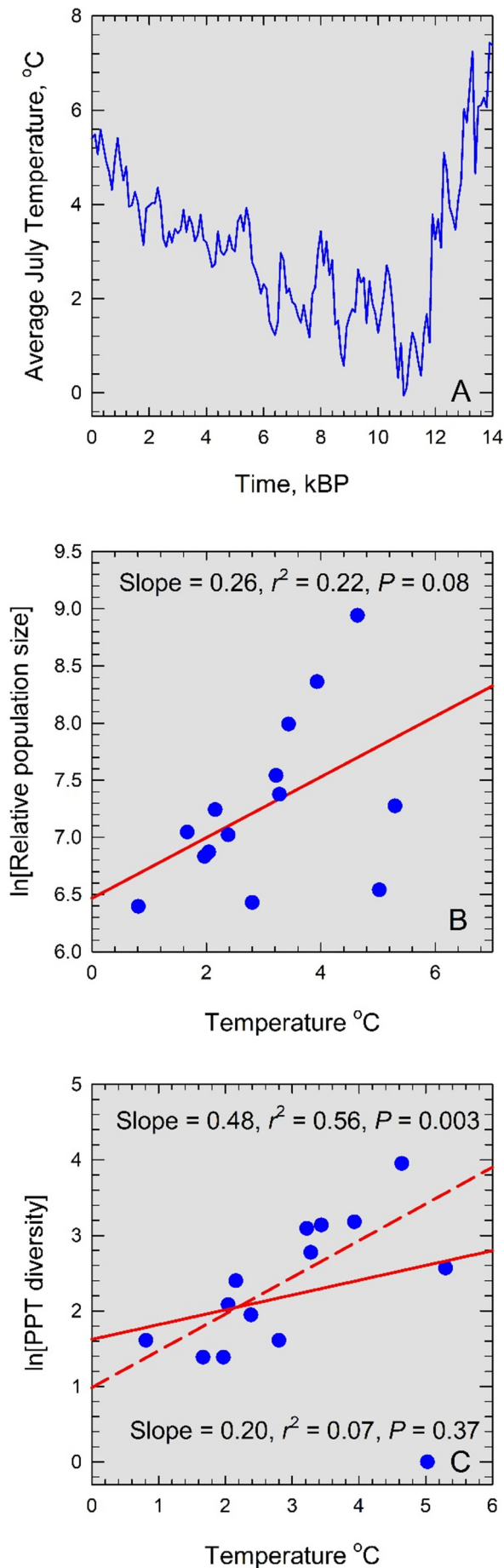
region. Indeed, many archaeologists have argued technological diversification is a response to ecological risk (Bamforth and Bleed, 1997; Buchanan et al., 2016b; Collard et al., 2005, 2011, 2013; Hiscock, 1994; Torrence, 1983). The complexity of toolkits is seen as a technological response to the risk of resource failure (Collard et al., 2005, 2011, 2013), and at a broader scale, the number of projectile point types captures the diversity of adaptive solutions to larger-scale changes in climates (Buchanan et al., 2016b). Fig. 10C would seem to support this scenario as there is a strong relationship between diversity and temperature over the Holocene.

Other researchers emphasize that technological innovation rates are related to population size (Boserup, 1981; Kline and Boyd, 2010; Powell et al., 2009; Shennan, 2001). This is clearly the case in modern urbanized industrialized economies where innovation rates exhibit increasing returns to scale with the population size of cities (Bettencourt and West, 2010; Bettencourt et al., 2007, 2014). Moreover, recent research suggests similar trends are characteristic of innovation rates in both ancient and historic cities (Cesaretti et al., 2016; Hanson et al., 2017; Ortman et al., 2014, 2015, 2016; Ortman and Coffey, 2015, 2017). In our results, diversity does increase significantly with population size (Fig. 9B), as well as temperature (Fig. 10C). Therefore, these results suggest a scenario where projectile point type diversity increases in western North America over time as populations grow and as the climate warms.

The projectile point types that exhibit the largest spatial distribution in western North America are not those that are the longest lived, but the oldest, namely Clovis, Folsom, Plainview, Agate Basin, and Scottsbluff, all Paleoindian types. This observation has interesting implications for understanding the diffusion of projectile point types through populations (Buchanan et al., 2017); because spatial extent is not a function of longevity (Fig. 6B), the diffusivity of a projectile point type must be limited by the size of the social network within which it occurs. Thus, successful new projectile point types reach saturation in social networks long before they are replaced by new innovations.

An alternative hypothesis for the concavity of projectile point longevity (Fig. 6) could be research bias if it were the case that the majority of specialists focused either on the initial stages of human occupation in North America, or on the later stages related to the development of agriculture and the protohistoric and historic periods. If so, the early- to mid-Holocene would be relatively understudied resulting in fewer archaeologists specializing in early- to mid-Holocene projectile point technologies. If so, the increased longevity of projectile points would result from decreasing research focus leading to fewer recognized types. This is a constant potential source of bias in any archaeological study, especially over long expanses of time. However, our data provides no evidence of sampling bias over time. Fig. 3 shows that there is no significant difference between the probability distributions of projectile point type diversity and the radiocarbon record over time (Mann-Whitney: $P = 0.69$), suggesting both are sampled at the same frequency.

The rates of diversification we report here are remarkably similar to the branching rates of languages, as measured by cognate replacement rates, $\sim 3 \times 10^{-4} \mathrm{yr}^{-1}$ (Pagel et al., 2007). Projectile point types therefore seem to evolve on the same temporal scale as languages, approximately two orders of magnitude slower than maximum instantaneous population growth rates ($\sim 0.04^{-yr}$). This finding is consistent with recent research that shows that the spatial extents of projectile points in the archaeological record are significantly greater than ethnohistoric tribal areas in North America, and more consistent with regional affiliations of languages, or language phyla (Buchanan et al.,

Fig. 10. Temperature estimates in the southwest US over 14,000 years. A) Time series of average July temperature estimates. B) Estimated population sizes plotted as a function of average temperature estimates averaged over 1000 year increments. C) Projectile point diversity plotted as a function of binned temperature estimates.

2017). It is not hard to imagine that aspects of lithic technology crucial to the economics of foraging, such as the design and engineering of hunting weaponry, maybe under as much stabilizing cultural selection as the core cognates in languages, informational elements critical to the accurate transmission of information among individuals and across generations. In any case, the evolutionary rate of projectile point type diversification occurs on the level of millennia, and at spatial scales much greater than individual populations.

Here we have shown projectile point type diversification in western North America occurred at similar rates in time and space, which combine to describe a diversification process as a rich, fractal-like space-filling process. The rate of diversification of point types is similar to rates of linguistic diversification suggesting that both may be related to the same principles of ethnolinguistic evolution. Our results show how the diversification process was related to long-term population growth in the region, and constrained by climate change over the Holocene.

Acknowledgements

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2019.01.029.

References

Ahlerup, P., Olsson, O., 2012. The roots of ethnic diversity. J. Econ. Growth 17, 71–102.

Atkinson, Q.D., 2011. Phonemic diversity supports a serial founder effect model of language expansion from Africa. Science 332, 346–349.

Axelsen, J.B., Manrubia, S., 2014. River Density and Landscape Roughness Are Universal Determinants of Linguistic Diversity. Proc. R. Soc. B. The Royal Society, pp. 20133029.

Bailey, D.H., Hamilton, M.J., Walker, R.S., 2012. Latitude, population size, and the language-farming dispersal hypothesis. Evol. Ecol. Res. 14, 1057–1067.

Bamforth, D.B., Bleed, P., 1997. Technology, flaked stone technology, and risk. Archeol. Pap. Am. Anthropol. Assoc. 7, 109–139.

Bellwood, P., 2005. First Farmers: The Origins of Agricultural Societies. Blackwell.

Bellwood, P.S., Renfrew, C., 2002. Examining the Farming/Language Dispersal Hypothesis. McDonald Institute for Archaeological Research.

Berezkin, Y., 2005. The cosmic hunt: variants of a Siberian-North-American myth. Folklore 31, 79–100.

Berezkin, Y.E., 2009. Why are people mortal? World mythology and the "out-of-africa" scenario. In: Anc. Hum. Migr. Multidiscip. Approach Salt Lake City. 242.

Bettencourt, L., West, G., 2010. A unified theory of urban living. Nature 467, 912–913.

Bettencourt, L.M.A., Lobo, J., Helbing, D., Kühnert, C., West, G.B., 2007. Growth, innovation, scaling, and the pace of life in cities. Proc. Natl. Acad. Sci. 104, 7301–7306. https://doi.org/10.1073/pnas.0610172104.

Bettencourt, L.M., Samaniego, H., Youn, H., 2014. Professional diversity and the productivity of cities. Sci. Rep. 4.

Bond, G., Showers, W., Cheseby, M., Lotti, R., Almasi, P., Priore, P., Cullen, H., Hajdas, I., Bonani, G., 1997. A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. Science 278, 1257–1266.

Boserup, E., 1981. Population and Technological Change: A Study of Long-Term Trends.

Bouckaert, R., Lemey, P., Dunn, M., Greenhill, S.J., Alekseyenko, A.V., Drummond, A.J., Gray, R.D., Suchard, M.A., Atkinson, Q.D., 2012. Mapping the origins and expansion of the Indo-European language family. Science 337, 957–960.

Braje, T.J., Dillehay, T.D., Erlandson, J.M., Klein, R.G., Rick, T.C., 2017. Finding the first Americans. Science 358, 592–594. https://doi.org/10.1126/science.aao5473.

Braje, T.J., Rick, T.C., Dillehay, T.D., Erlandson, J.M., Klein, R.G., 2018. Arrival routes of first Americans uncertain—response. Science 359, 1225. https://doi.org/10.1126/science.aar8645.

Bryson, R.U., Bryson, R.A., Ruter, A., 2006. A calibrated radiocarbon database of late Quaternary volcanic eruptions. eEarth Discuss. 1, 123–134.

Buchanan, B., 2006. An analysis of Folsom projectile point resharpening using quantitative comparisons of form and allometry. J. Archaeol. Sci. 33, 185–199.

Buchanan, B., Collard, M., 2010a. A geometric morphometrics-based assessment of blade shape differences among Paleoindian projectile point types from western North America. J. Archaeol. Sci. 37, 350–359.

Buchanan, B., Collard, M., 2010b. An assessment of the impact of resharpening on Paleoindian projectile point blade shape using geometric morphometric techniques. In: New Perspectives on Old Stones. Springer, pp. 255–273.

Buchanan, B., Hamilton, M.J., 2009. A formal test of the origin of variation in north American early Paleoindian projectile points. Am. Antiq. 74, 279–298.

Buchanan, B., Collard, M., Hamilton, M.J., O'Brien, M.J., 2011. Points and prey: a quantitative test of the hypothesis that prey size influences early Paleoindian projectile point form. J. Archaeol. Sci. 38, 852–864.

Buchanan, B., Hamilton, M.J., Kilby, J.D., Gingerich, J.A.M., 2016a. Lithic networks reveal early regionalization in late Pleistocene North America. J. Archaeol. Sci. 65, 114–121. https://doi.org/10.1016/j.jas.2015.11.003.

Buchanan, B., O'Brien, M.J., Collard, M., 2016b. Drivers of technological richness in prehistoric Texas: an archaeological test of the population size and environmental risk hypotheses. Archaeol. Anthropol. Sci. 8, 625–634.

Buchanan, B., Hamilton, M.J., Hartley, J.C., Kuhn, S.L., 2017. Investigating the scale of prehistoric social networks using culture, language, and point types in western North America. Archaeol. Anthropol. Sci. 1–9.

Burnside, W.R., Brown, J.H., Burger, O., Hamilton, M.J., Moses, M., Bettencourt, L., 2012. Human macroecology: linking pattern and process in big-picture human ecology. Biol. Rev. 87, 194–208.

Cashdan, E., 2001. Ethnic diversity and its environmental determinants: effects of climate, pathogens, and habitat diversity. Am. Anthropol. 103, 968–991.

Cavalli-Sforza, L.L., Menozzi, P., Piazza, A., 1993. Demic expansions and human evolution. Science 259, 639–646.

Cesaretti, R., Lobo, J., Bettencourt, L.M., Ortman, S.G., Smith, M.E., 2016. Population-area relationship for medieval European cities. PLoS One 11, e0162678.

Collard, I.F., Foley, R.A., 2002. Latitudinal patterns and environmental determinants of recent human cultural diversity: do humans follow biogeographical rules? Evol. Ecol. Res. 4, 371–383.

Collard, M., Kemery, M., Banks, S., 2005. Causes of toolkit variation among hunter-gatherers: a test of four competing hypotheses. Can. J. Archaeol. 1–19.

Collard, M., Buchanan, B., Hamilton, M.J., O'Brien, M.J., 2010. Spatiotemporal dynamics of the Clovis–Folsom transition. J. Archaeol. Sci. 37, 2513–2519.

Collard, M., Buchanan, B., Morin, J., Costopoulos, A., 2011. What drives the evolution of hunter–gatherer subsistence technology? A reanalysis of the risk hypothesis with data from the Pacific Northwest. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 366, 1129–1138.

Collard, M., Buchanan, B., O'Brien, M.J., Scholnick, J., 2013. Risk, mobility or population size? Drivers of technological richness among contact-period western North American hunter–gatherers. Philos. Trans. R. Soc. B 368, 20120412.

Costa, A.G., 2010. A geometric morphometric assessment of plan shape in bone and stone Acheulean bifaces from the Middle Pleistocene site of Castel di Guido, Latium, Italy. In: New Perspectives on Old Stones. Springer, pp. 23–41.

Currie, T.E., Mace, R., 2009. Political complexity predicts the spread of ethnolinguistic groups. Proc. Natl. Acad. Sci. 106, 7339–7344.

Currie, T.E., Mace, R., 2012. The evolution of ethnolinguistic diversity. Adv. Complex Syst. 15, 1150006.

Currie, T.E., Greenhill, S.J., Gray, R.D., Hasegawa, T., Mace, R., 2010. Rise and fall of political complexity in island South-East Asia and the Pacific. Nature 467, 801.

Currie, T.E., Meade, A., Guillon, M., Mace, R., 2013. Cultural phylogeography of the bantu languages of sub-Saharan Africa. Proc. R. Soc. B 280, 20130695.

Da Silva, S.G., Tehrani, J.J., 2016. Comparative phylogenetic analyses uncover the ancient roots of Indo-European folktales. R. Soc. Open Sci. 3, 150645.

Danzeglocke, U., 2018. CalPal - radiocarbon calibration online [WWW Document]. URL. http://www.calpal-online.de/, (accessed 3.19.18).

Dean, W.E., Ahlbrandt, T.S., Anderson, R.Y., Bradbury, J.P., 1996. Regional aridity in North America during the middle Holocene. The Holocene 6, 145–155. https://doi.org/10.1177/095968369600600202.

d'Huy, J., 2013a. A Cosmic Hunt in the Berber sky: a phylogenetic reconstruction of a Palaeolithic mythology. Cah. AARS 93–106.

d'Huy, J., 2013b. Polyphemus (Aa. Th. 1137): a phylogenetic reconstruction of a prehistoric tale. Nouv. Mythol. Comparée 1 (http–nouvellemythologiecomparee).

d'Huy, J., 2013c. A phylogenetic approach of mythology and its archaeological consequences. Rock Art Res. 30, 115–118.

Diamond, J., Bellwood, P., 2003. Farmers and their languages: the first expansions. Science 300, 597–603.

Eren, M.I., Lycett, S.J., 2012. Why Levallois? A morphometric comparison of experimental 'preferential'Levallois flakes versus debitage flakes. PLoS One 7, e29273.

Fort, J., 2012. Synthesis between demic and cultural diffusion in the Neolithic transition in Europe. Proc. Natl. Acad. Sci. 109, 18669–18673.

Fort, J., Pujol, T., Cavalli-Sforza, L.L., 2004. Palaeolithic populations and waves of advance. Camb. Archaeol. J. 14, 53–61.

Gajewski, K., Munoz, S., Peros, M., Viau, A., Morlan, R., Betts, M., 2011. The Canadian archaeological radiocarbon database (Card): archaeological ^{14}C dates in North America and their Paleoenvironmental context. Radiocarbon 53, 371–394. https://doi.org/10.1017/S0033822200056630.

Gavin, M.C., Botero, C.A., Bowern, C., Colwell, R.K., Dunn, M., Dunn, R.R., Gray, R.D., Kirby, K.R., McCarter, J., Powell, A., 2013. Toward a mechanistic understanding of linguistic diversity. Bioscience 63, 524–535.

Gray, R.D., Atkinson, Q.D., 2003. Language-tree divergence times support the Anatolian theory of Indo-European origin. Nature 426, 435.

Greenhill, S.J., Atkinson, Q.D., Meade, A., Gray, R.D., 2010. The shape and tempo of language evolution. Proc. R. Soc. Lond. B Biol. Sci. 277, 2443–2450.

Grollemund, R., Branford, S., Bostoen, K., Meade, A., Venditti, C., Pagel, M., 2015. Bantu expansion shows that habitat alters the route and pace of human dispersals. Proc. Natl. Acad. Sci. 112, 13296–13301.

Hamilton, M.J., Buchanan, B., 2007. Spatial gradients in Clovis-age radiocarbon dates across North America suggest rapid colonization from the north. Proc. Natl. Acad. Sci. 104, 15625–15630.

Hamilton, M.J., Buchanan, B., 2010. Archaeological support for the three-stage expansion of modern humans across northeastern Eurasia and into the Americas. PLoS One 5, e12472.

Hamilton, M.J., Walker, R.S., 2018. A stochastic density-dependent model of long-term population dynamics in hunter-gatherer populations. Evol. Ecol. Res. 19, 85–102.

Hanson, J.W., Ortman, S.G., Lobo, J., 2017. Urbanism and the division of labour in the Roman empire. J. R. Soc. Interface 14, 20170367. https://doi.org/10.1098/rsif.2017.0367.

Harrison, S.P. al, Kutzbach, J.E., Liu, Z., Bartlein, P.J., Otto-Bliesner, B., Muhs, D., Prentice, I.C., Thompson, R.S., 2003. Mid-Holocene climates of the Americas: a dynamical response to changed seasonality. Clim. Dyn. 20, 663–688.

Henrich, J., McElreath, R., 2003. The evolution of cultural evolution. Evol. Anthropol. Issues News Rev. 12, 123–135.

Hiscock, P., 1994. Technological responses to risk in Holocene Australia. J. World Prehist. 8, 267–292.

Hiscock, P., 2013. Occupying new lands: global migrations and cultural diversification with particular reference to Australia. In: Paleoamerican Odyssey, pp. 3–11.

Holliday, V.T., 1997. Paleoindian Geoarchaeology of the Southern High Plains. University of Texas Press.

Iovita, R., 2011. Shape variation in Aterian tanged tools and the origins of projectile technology: a morphometric perspective on stone tool function. PLoS One 6, e29029.

Iovita, R., McPherron, S.P., 2011. The handaxe reloaded: a morphometric reassessment of Acheulian and middle Paleolithic handaxes. J. Hum. Evol. 61, 61–74.

Justice, N.D., 2002a. Stone Age Spear and Arrow Points of the Southwestern United States. Indiana University Press.

Justice, N.D., 2002b. Stone Age Spear and Arrow Points of California and the Great Basin. Indiana University Press.

Karlin, S., 2014. A First Course in Stochastic Processes. Academic press.

Kennett, D.J., Culleton, B.J., Kennett, J.P., Erlandson, J.M., Cannariato, K.G., 2007. Middle Holocene climate change and human population dispersal in western North America. In: Climate Change and Cultural Dynamics. Elsevier, pp. 531–557.

Kimmel, M., Axelrod, D.E., 2016. Branching Processes in Biology. Springer Publishing Company, Incorporated.

Kline, M.A., Boyd, R., 2010. Population size predicts technological complexity in Oceania. Proc. R. Soc. Lond. B Biol. Sci. 277, 2559–2564.

Kummu, M., Varis, O., 2011. The world by latitudes: a global analysis of human population, development level and environment across the north–south axis over the past half century. Appl. Geogr. 31, 495–507.

Lyman, R.L., O'Brien, M.J., 2000. Measuring and explaining change in artifact variation with clade-diversity diagrams. J. Anthropol. Archaeol. 19, 39–74.

Lyman, R.L., VanPool, T.L., O'Brien, M.J., 2008. Variation in North American dart points and arrow points when one or both are present. J. Archaeol. Sci. 35, 2805–2812.

Lyman, R.L., VanPool, T.L., O'Brien, M.J., 2009. The diversity of North American projectile-point types, before and after the bow and arrow. J. Anthropol. Archaeol. 28, 1–13.

Mace, R., Pagel, M., 1995. A latitudinal gradient in the density of human languages in North America. Proc. R. Soc. Lond. B 261, 117–121.

Madsen, D.B., 2004. Entering America: Northeast Asia and Beringia before the Last Glacial Maximum. University of Utah Press.

Maffi, L., 2005. Linguistic, cultural, and biological diversity. Annu. Rev. Anthropol. 34, 599–617.

Marsicek, J., Shuman, B.N., Bartlein, P.J., Shafer, S.L., Brewer, S., 2018. Reconciling divergent trends and millennial variations in Holocene temperatures. Nature 554, 92.

Meltzer, D.J., 2009. First Peoples in a New World: Colonizing Ice Age America. Univ of California Press.

Mesoudi, A., O'Brien, M.J., 2008a. The cultural transmission of Great Basin projectile-point technology I: an experimental simulation. Am. Antiq. 73, 3–28.

Mesoudi, A., O'Brien, M.J., 2008b. The cultural transmission of Great Basin projectile-point technology II: an agent-based computer simulation. Am. Antiq. 73, 627–644.

Michalopoulos, S., 2012. The origins of ethnolinguistic diversity. Am. Econ. Rev. 102, 1508–1539.

Nettle, D., 1999. Linguistic Diversity. Oxford University Press.

Nunn, C.L., 2011. The Comparative Approach in Evolutionary Anthropology and Biology. University of Chicago Press.

O'Brien, M.J., Darwent, J., Lyman, R.L., 2001. Cladistics is useful for reconstructing archaeological phylogenies: Palaeoindian points from the southeastern United States. J. Archaeol. Sci. 28, 1115–1136.

O'Brien, M.J., Lyman, R.L., Saab, Y., Saab, E., Darwent, J., Glover, D.S., 2002. Two issues in archaeological phylogenetics: taxon construction and outgroup selection. J. Theor. Biol. 215, 133–150.

Ortman, S.G., Coffey, G.D., 2015. Universal Scaling: Evidence From Village-Level Societies. SFI Working Paper 15-10-044 Santa Fe Institute, Santa Fe, NM. http://www.santafe.edu/media/workingpapers/15-11-044.pdf.[MES/JL].

Ortman, S.G., Coffey, G.D., 2017. Settlement scaling in middle-range societies. Am. Antiq. 82, 662–682.

Ortman, S.G., Cabaniss, A.H., Sturm, J.O., Bettencourt, L.M., 2014. The pre-history of urban scaling. PLoS One 9, e87902.

Ortman, S.G., Cabaniss, A.H., Sturm, J.O., Bettencourt, L.M., 2015. Settlement scaling and

increasing returns in an ancient society. Sci. Adv. 1, e1400066.

Ortman, S.G., Davis, K.E., Lobo, J., Smith, M.E., Bettencourt, L.M., Trumbo, A., 2016. Settlement scaling and economic change in the Central Andes. J. Archaeol. Sci. 73, 94–106.

Pagel, M., 2016. Anthropology: the long lives of fairy tales. Curr. Biol. 26, R279–R281.

Pagel, M., Mace, R., 2004. The cultural wealth of nations. Nature 428, 275.

Pagel, M., Atkinson, Q.D., Meade, A., 2007. Frequency of word-use predicts rates of lexical evolution throughout Indo-European history. Nature 449, 717–720.

Perreault, C., 2012. The pace of cultural evolution. PLoS One 7, e45150. https://doi.org/ 10.1371/journal.pone.0045150.

Pinhasi, R., Fort, J., Ammerman, A.J., 2005. Tracing the origin and spread of agriculture in Europe. PLoS Biol. 3, e410.

Polyak, V.J., Asmerom, Y., 2001. Late Holocene climate and cultural changes in the southwestern United States. Science 294, 148–151. https://doi.org/10.1126/science. 1062771.

Potter, B.A., Reuther, J.D., Holliday, V.T., Holmes, C.E., Miller, D.S., Schmuck, N., 2017. Early colonization of Beringia and northern North America: chronology, routes, and adaptive strategies. Quat. Int. 444, 36–55.

Potter, B.A., Beaudoin, A.B., Haynes, C.V., Holliday, V.T., Holmes, C.E., Ives, J.W., Kelly, R., Llamas, B., Malhi, R., Miller, S., Reich, D., Reuther, J.D., Schiffels, S., Surovell, T., 2018. Arrival routes of first Americans uncertain. Science 359, 1224–1225. https:// doi.org/10.1126/science.aar8233.

Powell, A., Shennan, S., Thomas, M.G., 2009. Late Pleistocene demography and the appearance of modern human behavior. Science 324, 1298–1301.

Rehfeld, K., Münch, T., Ho, S.L., Laepple, T., 2018. Global patterns of declining temperature variability from the Last Glacial Maximum to the Holocene. Nature. https:// doi.org/10.1038/nature25454.

Shennan, S., 2001. Demography and cultural innovation: a model and its implications for the emergence of modern human culture. Camb. Archaeol. J. 11, 5–16.

Steig, E.J., 1999. Mid-Holocene climate change. Science 286, 1485–1487. https://doi. org/10.1126/science.286.5444.1485.

Surovell, T.A., Brantingham, P.J., 2007. A note on the use of temporal frequency distributions in studies of prehistoric demography. J. Archaeol. Sci. 34, 1868–1877.

Surovell, T.A., Finley, J.B., Smith, G.M., Brantingham, P.J., Kelly, R., 2009. Correcting temporal frequency distributions for taphonomic bias. J. Archaeol. Sci. 36, 1715–1724.

Tehrani, J.J., 2013. The phylogeny of little red riding hood. PLoS One 8, e78871.

Thulman, D.K., 2012. Discriminating Paleoindian point types from Florida using landmark geometric morphometrics. J. Archaeol. Sci. 39, 1599–1607.

Torrence, R., 1983. Time budgeting and hunter-gatherer technology. Hunt.-Gatherer Econ. Prehist. 11–22.

Turchin, P., Currie, T.E., Whitehouse, H., François, P., Feeney, K., Mullins, D., Hoyer, D., Collins, C., Grohmann, S., Savage, P., 2018. Quantitative historical analysis uncovers a single dimension of complexity that structures global variation in human social organization. Proc. Natl. Acad. Sci. 115, E144–E151.

Viau, A.E., Gajewski, K., Sawada, M.C., Fines, P., 2006. Millennial-scale temperature variations in North America during the Holocene. J. Geophys. Res.-Atmos. 111, D09102. https://doi.org/10.1029/2005JD006031.

Walker, R.S., Hamilton, M.J., 2011. Social complexity and linguistic diversity in the Austronesian and Bantu population expansions. Proc. R. Soc. Lond. B Biol. Sci. 278, 1399–1404.

Wanner, H., Beer, J., Bütikofer, J., Crowley, T.J., Cubasch, U., Flückiger, J., Goosse, H., Grosjean, M., Joos, F., Kaplan, J.O., 2008. Mid-to Late Holocene climate change: an overview. Quat. Sci. Rev. 27, 1791–1828.