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Drivers of technological richness in prehistoric Texas: an archaeological test of the population size and environmental risk hypotheses

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Abstract This paper reports a study that sheds light on an issue that is important for understanding human behavioral evolution—the factors that influence hunter-gatherers' decisions regarding the number and degree of specialization of their tools. Two primary drivers of technological richness and complexity have been proposed in the anthropological literature: population size and environmental risk. In general, ethnographic studies tend to support environmental risk as the primary driver, whereas the limited number of archaeological studies that have been carried out seem to support population size. These findings are difficult to reconcile because problems exist for both sets of studies. The present study was designed with these problems in mind. We used an archaeological dataset to test which of the hypothesized driving factors—population size or environmental risk—best explains changes in technological richness. More specifically, we investigated whether changes in the number of point types in Texas from the first occupation more than 13,000 years ago to the Late Prehistoric period, around 400 years ago, are better explained by environmental risk or by population size. Bivariate correlations and a generalized linear model indicate that temporal changes in point-type richness in Texas are significantly associated with changes in one of our proxies of risk—global temperature. We found no relationship between temporal changes in point-type richness and changes in population size. Thus, the results derived from this study are consistent with the environmental risk hypothesis and inconsistent with the population size hypothesis.

Keywords Technological richness · Environmental risk hypothesis · Population size hypothesis · Texas · Point types

Introduction

This paper reports a study designed to shed light on an issue that is important for understanding human behavioral evolution—the factors that influence hunter-gatherers' decisions regarding the number and degree of specialization of their tools. Four terms are important to our discussion: *toolkit richness*, *toolkit complexity*, *technounit*, and *toolkit structure*. "Toolkit richness" refers to the total number of tools used by a group. Other researchers have referred to the total number of tools as "toolkit diversity" (e.g., Collard et al. 2005; Shott 1986; Torrence 1983), but as Collard et al. (2013a, b, c) have pointed out, this term is potentially confusing. In ecology—the discipline from which archaeologists borrowed the term (Leonard and Jones 1989)—"diversity" has two dimensions: "richness" and "evenness." The former refers to the number of taxa in a community, landscape, or region; the latter refers to how similar the taxa in a community, landscape, or region are in terms of numbers of individuals. To reduce the potential for confusion, we refer to the total number of tools as toolkit richness rather than toolkit diversity. The terms "toolkit complexity" and "technounit" originate with pioneering efforts of Oswalt (1973, 1976) to quantify traditional food-getting toolkits. Oswalt defined toolkit complexity as the total number of technounits in a toolkit, where a technounit is an

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"integrated, physically distinct and unique structural configuration that contributes to the form of a finished artifact" (1976:38). "Toolkit structure" refers to both the richness and complexity of a toolkit (Torrence 1983).

The scale of variation in the richness and complexity of the toolkits used by hunter-gatherers is substantial. This can be seen clearly in the ethnographic data on subsistence technology presented in Oswalt's (1976) *An Anthropological Analysis of Food-Getting Technology.* Oswalt calculated that the Tiwi of northern Australia used 11 tools with 14 distinct parts to obtain food, whereas the Ingalik/Deg Xit'an of Alaska employed 54 tools with 296 distinct parts to achieve the same end. Marked variation in the number and complexity of the tools used by hunter-gatherers is also visible in the archaeological record. Excavations of sites on different continents and from different time periods show that prehistoric hunter-gatherer toolkits ranged from only a few simple tools to many multifunctional tools (Klein 2009; Shea 2013).

Two primary drivers of technological richness and complexity are under discussion at the moment: population size and environmental risk (Collard et al. 2005, 2012, 2013a, b). The notion that population size affects technological complexity was introduced by Henrich (2004), who developed a formal model to demonstrate that population size can affect the probability of more complex skills being invented. In the model, learners preferentially copy the most skilled practitioner with error. The probability distribution that determines the amount of error is such that a learner will only occasionally get a better result than the previous best. The likelihood of this occurring is partly dependent on population size because in large populations, even improbable events occur occasionally, and the larger the population, the more likely this is. Consequently, technological complexity will be influenced by population size. The following year, Collard et al. (2005) extended the population size hypothesis to technological richness. They did so in light of modeling work carried out by Shennan (2001), who showed that larger populations have an advantage over smaller ones when it comes to cultural innovation as a result of the decreasing role of sampling effects as populations get larger. When populations are large, there is a greater probability of fitness-enhancing innovations being maintained and deleterious ones lost than when populations are small.

The results of a number of other recent modeling studies suggest that population size has the potential to impact technological richness and complexity. Premo and Kuhn (2010) used agent-based modeling to explore the effects of population size on technological richness and complexity. Their model incorporated local group extinctions and investigated traits that do not affect fitness. Complementing the results of Henrich (2004), Premo and Kuhn showed that cultural trait richness, differences in cultural traits among groups, and cumulative cultural change are strongly affected by population loss. Building on the model of Henrich (2004), Mesoudi (2011) demonstrated that similar results are achieved even when acquisition costs are taken into account. However, in the model of Mesoudi, acquisition costs result in a plateau effect for direct and indirect modes of social learning. Direct social learning reaches a plateau around a population of 100 whereas indirect social learning reaches a plateau with a population of 1000. Most recently, Kobayashi and Aoki (2012) modified the model of Henrich (2004) to include overlapping generations. They found that the effect of population size on cultural evolution is amplified when generational overlap is taken into account.

Before we turn to the risk hypothesis, it is worth noting that the robustness of the population size hypothesis has been challenged on theoretical grounds recently. Bentley and O'Brien (2011) have demonstrated that the impact of population size in the model of Henrich (2004) is dependent on two potentially problematic assumptions—the existence of extreme selectivity for the skill under consideration and an exponential distribution of the skill within the population. Last year, Querbes et al. (2014) highlighted another problem with the population size hypothesis. They examined the effects of different definitions of cultural complexity and found very limited support for the hypothesis when cultural complexity involves not only just a trait's number of components but also the number of interactions between these components. Together, these papers clearly suggest that we are still some way from fully understanding the circumstances in which population size should affect technological richness and complexity.

The risk hypothesis has its roots in a study by Torrence (1983), in which she suggested that as time stress increases, hunter-gatherers produce more-specialized tools because such tools tend to be more effective. Specialized tools usually have more parts than generalized tools, and so, the production of specialized tools increases both toolkit richness and toolkit complexity, leading to an association between toolkit structure and time stress. Subsequently, Torrence (1989) argued that, contrary to what she previously believed, time stress is only a proximate cause of toolkit variation and that the ultimate cause is risk of resource failure. The use of more-specialized, and therefore more-elaborate, tools reduces risk of resource failure. Thus, groups that experience a high risk of resource failure will produce toolkits that are richer and more complex than will groups that experience lower risk of resource failure.

Both the population size hypothesis and the risk hypothesis have been tested with empirical data, and an intriguing contrast has emerged from this work. Studies that have tested the hypotheses with data from ethnographically documented hunter-gatherers have generally supported the risk hypothesis (Collard et al. 2005, 2013a, b, c; Henrich 2006; Read 2008). Collard et al. (2005), for example, compiled data for a global sample of 20 hunter-gatherer groups and then used stepwise regression to test the population size hypothesis, the risk hypothesis, and two other hypotheses. They found that risk—measured using effective temperature and net above-ground productivity as proxies—was the only one of the four hypothesized drivers to be supported. Henrich (2006) used the same dataset as Collard et al. (2005) to examine toolkit richness, toolkit complexity, and a related variable that he called "the maximum complexity of technology," which is the sum of technounits in the most complex tool in each of the four main categories of technology represented in a dataset: instruments, weapons, tended facilities, and untended facilities. Using stepwise regression, Henrich found that the technological variables were significantly associated only with effective temperature, which was one of his proxies for risk. Read (2008) also tested the environmental hypothesis as part of an investigation into factors that drive variation in toolkit structure among recent hunter-gatherers. Like Collard et al. (2005) and Henrich (2006), he found support for the environmental risk hypothesis. He also found that mobility had a secondary effect on toolkit structure. A few years later, Collard et al. (2013a) expanded the dataset used by Collard et al. (2005), Henrich (2006), and Read (2008) by adding toolkit measures for a further 29 hunter-gatherer groups and tested several competing hypotheses, including the population size hypothesis and the risk hypothesis, at the global, continental, and regional scales. The results of their analyses supported only the risk hypothesis. Most recently, Collard et al. (2013b) tested the environmental risk hypothesis as part of a study that focused on the drivers of technological richness among 85 recent hunter-gatherer groups from western North America. They found that the total number of material items and techniques was correlated with both a proxy for risk—mean rainfall for the driest month—and population size. However, the direction of the relationship between technological richness and population size was the opposite of the one predicted by the population size hypothesis (it was negative rather than positive).

So far, the only ethnographic data-based study that does not support the risk hypothesis is one by Collard et al. (2011), which examined hunter-gatherer toolkit richness and complexity in groups from the Pacific Northwest. This study explored the risk hypothesis at a regional rather than a global scale and found that risk did not affect toolkit richness and complexity in comparisons of groups from the coast with groups from the plateau. The coast and plateau regions of the Pacific Northwest have different environmental risk regimes. The plateau is a riskier environment, and groups in this area were expected to have richer and more complex toolkits than groups on the coast. In their discussion of these unexpected findings, Collard et al. (2011) proposed that the effects of environmental risk may be scale dependent, such that when risk differences are large, risk is the most important influence on toolkit structure variation, but when risk differences are small, other factors are more influential as determinants of toolkit structure. They suggested that differences in risk between the populations on the coast and plateau of the Pacific Northwest may be too small for risk to drive differences in toolkit structure. Important for present purposes, Collard et al. (2013b) included the same groups in their sample and found that population size did not have a significant effect on toolkit richness or toolkit complexity. Thus, variation in toolkit structure among Pacific Northwest groups supports neither the risk hypothesis nor the population size hypothesis.

In contrast to the ethnographic data-based studies, the authors of the two studies in which the causes of variation in technological complexity have been investigated with archaeological data concluded that their analyses support the population size hypothesis. Powell et al. (2009) examined the population size hypothesis with data pertaining to the Palaeolithic. They used molecular data to estimate when different regions of the world would have reached the same population density as Europe at the start of the Upper Palaeolithic and then compared those estimates with the timing of the appearance of markers of modern behavior in each region. They reported finding a correspondence between the timing of the crossing of the density threshold and the timing of the appearance of markers of modern behavior in sub-Saharan Africa, North Africa, and the Levant. Powell et al. (2009) concluded that increased population size drove complex technology. In a similar vein, Mackay et al. (2014) recently compiled archaeological data from South Africa and matched the occurrences of complex lithic and osseous technologies, ornaments, motifs, and abstract designs with estimates of population interactions and climatic changes. They found that there was a correlation between periods of high population interaction with periods of increased ornamentation and symbolic expression in the late Pleistocene. Based on this, Mackay et al. suggested that population interaction, which in effect creates a larger population size, was the main driver of increased technological complexity.

The discrepancy between the findings of the ethnographic studies and the archaeological studies cannot be easily resolved because problems exist for both sets of studies. The two archaeological studies that assert support for the population size hypothesis have, in fact, yielded mixed results. The study of Powell et al. (2009), while supporting the population size hypothesis in three regions, does not support the hypothesis in three other regions. Their results indicate that the timing of the crossing of the population density threshold in southern, northern, and central Asia did not coincide with the appearance of complex technology. The results of Mackay et al. (2014) also are equivocal on closer inspection. They found a match between periods of increased long-distance population interaction and increased use of complex technologies and cultural elaboration during two Middle Stone Age periods but not at other times, most notably during the Late Stone Age. On the other hand, the ethnographic studies are limited to the analysis of very short time spans. The data for these studies come primarily from ethnohistorical accounts. These are essentially static "snapshots" of the toolkits used by indigenous groups as they were documented by ethnographers. It is unclear if the patterns documented in the ethnohistorical record are representative of long-term technological evolution.

The study reported here was designed with these issues in mind. We used an archaeological dataset to quantitatively test which of the hypothesized driving factors—risk or population size—best explains changes in technological richness. Specifically, we investigated whether changes in the number of point types in Texas from the first occupation more than 13,000 years ago to the Late Prehistoric period, around 400 years ago, are better explained by the risk hypothesis or by the population size hypothesis. We used Texas as our sampling area because it has a large number of point types for which there is reasonably good temporal control. We focused on points because they are easily recognized in archaeological assemblages and are ubiquitous throughout the spatial and temporal range of our study. We carried out two sets of analyses to evaluate the relationship between variation in the number of point types per archaeological period and variation in a proxy for population size and two proxies for environmental risk, one related to global temperature and the other to regional precipitation. The test prediction for the population size hypothesis was that the number of point types should be positively correlated with population size independent of any correlation between the number of point types and the proxies for environmental risk. Given the environmental characteristics of Texas, we assumed that risk increased as temperature increased and as the amount of precipitation decreased. We also assumed that risk must have an independent effect on the number of point types. Thus, the test prediction for the risk hypothesis was that the number of point types should correlate positively with global temperature and negatively with regional precipitation, and those correlations should be independent of any correlation between the number of point types and population size.

Prehistoric point types usually exhibit multiple morphological differences. These differences represent innovations. Some of the innovations are likely to have been functional, meaning that they improved the performance of the relevant point type; others were probably neutral, meaning that they did not affect the point type's performance. In order to test some hypotheses, it is important to differentiate between these two types of innovation, but it is not necessary to do so when testing between the population size and risk hypotheses. The population size hypothesis avers that both functional and neutral innovations will be affected by population size (Premo and Kuhn 2010; Shennan 2001). Thus, if the population size hypothesis is correct, there should be a positive correlation between the number of point types and population size regardless of whether the innovations are functional or neutral. The corollary of this is that finding an association between number of point types and population size supports the population size hypothesis, whereas failure to find such an association refutes it. In contrast to the population size hypothesis, the risk hypothesis differentiates between functional and neutral traits. It contends that only functional innovations will be affected by environmental risk. However, this simply complicates the explanation of a failure to support the hypothesis rather than undermining confidence in a positive outcome (i.e., the discovery of a correlation between the number of point types and proxies of environmental risk). It means that a failure to find an association between the number of point types and proxies of environmental risk could be due to either the majority of innovations being functional but culturally selected in relation to some other factor, or neutral.

Materials and methods

The point-type data that we used are from *A field guide to stone artifacts of Texas Indians* of Turner and Hester (1999). This book recognizes seven prehistoric time periods and assigns point types to one or more of them (Table 1). We allowed point types to be counted multiple times in cases when types spanned more than one period. The total number of point types reported by Turner and Hester is 130, 93 of which are identified as darts and 37 as arrows. When we tallied the types by time period and allowed for types spanning more than one time period to be counted several times, the number of types totaled 166, with 129 classified as darts and 37 as arrows.

Some researchers may object to our decision to use point types as the unit of analysis because types are arbitrary classification units devised by researchers (O'Brien and Lyman 2002). This is not an unreasonable concern. Types are often created by different researchers for different purposes, and as a consequence, there may be different levels of variation within and among types. However, given the broad temporal and spatial scale of our study, this is likely to be a problem only if there is a systemic bias in the way researchers defined types for particular time periods. We can find no evidence to suggest that such a bias exists.

Table 1 Number of Texas point types by time period defined by Turner and Hester (1999), age ranges, and regional and global environmental risk proxy data

Time period	Number of point types	Uncalibrated age range from Turner and Hester (1999)	Calibrated age range using Calib 7.0	Regional environmental risk proxy: carbon-13	Global environmental risk proxy: oxygen-18
Early Paleoindian	2	11,200–10,200[a]	13,060–11,910[a]	–4.035	–3.486
Late Paleoindian	19	10,200–8000	11,910–8854	–7.985	–1.540
Early Archaic	27	8000–4500	8854–5142	–6.36	0.347
Middle Archaic	30	4500–3000	5142–3185	–5.96	0.116
Late Archaic	32	3000–2300	3185–1523	–8.19	–0.043
Transitional Archaic	16	2300–1300	1523–1174	–6.77	–0.184
Late Prehistoric	40	1300–350	1174–404	–3.73	–0.163

The calibrated age ranges were calculated using Calib 7.0 and the IntCal13 calibration curve (Stuiver et al. 2013). The regional environmental risk proxy data come from the analysis of Humphrey and Ferring (1994) of sediment cores in north-central Texas. The proxy is for precipitation and is based on measures of isotope carbon-13. The global environmental risk proxy data are from isotope oxygen-18 measures taken from the Vostok ice core in Antarctica

[a] These age ranges do not include pooled dates from the Aubrey site in north-central Texas. Including those dates extends the early end of the range to approximately 13,387 cal BP (Haynes et al. 2007)

We used two proxies for risk. One was a measure of global temperature taken from the Vostok (Antarctica) ice core (Petit et al. 1999; Table 1). Measures of oxygen isotope 18 were taken from dated ice layers (NOAA). We averaged multiple measures from each time period for the global environmental record. The other risk proxy was a regional record of climate change derived from the stable carbon isotope study of Humphrey and Ferring (1994) of sediment cores from the Aubrey site in Denton County, north-central Texas. Humphrey and Ferring published measures of stable carbon isotope 13 per mil relative to the standard PDB, as they occur in dated strata at the site (Table 1). When multiple carbon-13 measures were available for a time period, we averaged them. Carbon-13 is a proxy for precipitation, with measures closer to zero indicative of a drier climate and increasing negative measures indicative of a wetter climate. For the purposes of testing the risk hypothesis, we assumed that decreasing precipitation and increasing temperature coincided with increasing risk because drier and hotter environments in Texas, such as large areas of southwestern Texas, have less biomass available, which translates into less subsistence resources available for human foragers.

The prehistoric population of the area that corresponds to the modern state of Texas is the metapopulation for this study. As a proxy for population size, we used the number of sites per time period, which we calculated based on dates in the Canadian Archaeological Radiocarbon Database (CARD; www.canadianarchaeology.ca/radiocarbon/card/card.htm). We extracted 544 dates, after which we removed radiocarbon dates labeled as anomalous—those that were either too young or too old relative to the accepted target age. Following methods discussed by Shennan and Edinborough (2007) and Buchanan et al. (2008), we used a pooled mean date for site occupations or discrete cultural components with multiple radiocarbon assays. We did this to prevent occupations with multiple dates from biasing our results. Pooled mean dates were calculated from uncalibrated dates using the Calib 7.0 program and the IntCal13 calibration curve (Stuiver et al. 2013). After pooling radiocarbon dates from occupations with multiple dates, our dataset comprised 121 radiocarbon-dated occupations.

We opted to use a simple count of radiocarbon-dated occupations as our proxy for population size rather than apply a taphonomic correction that accounts for the actions of destruction and erosion that disproportionately effects site representation with increasing age (Shennan et al. 2013; Surovell et al. 2009). We did this for two reasons. First, the rate of taphonomic destruction of archaeological sites in Texas is unknown, and therefore, any rate of destruction used to estimate this process would be merely a guess. Second, one of the earliest time periods in our dataset has more dated occupations than would be predicted by a taphonomic destruction model. A chi-square analysis of the number of dated occupations by time period shows that the Late Paleoindian sample (11,910–8854 cal BP) has significantly more dated occupations than expected if the numbers of dated occupations were evenly distributed among the seven time periods (χ^2=44.86, p<0.000; adjusted standardized residual for Late Paleoindian period is 4.74). This suggests that taphonomic destruction did not have a significant effect in Texas over the last 12,000 years. However, as a conservative measure, we ran an additional correlation analysis using the ranked number of sites by time period with the ranked number of types by time period.

After compiling the dataset, we carried out two analyses to test the predictions of the risk and population size hypotheses. The first consisted of a series of Pearson's bivariate correlations between the number of types and the risk and population size proxies. We used parametric correlations because the sample distributions approximated an underlying normal distribution (Kolmogorov-Smirnov test results: point types, $Z=0.463$, $p=0.985$; population size, $Z=0.519$, $p=0.950$; regional environment, $Z=0.456$, $p=0.985$; global environment, $Z=0.962$, $p=0.313$). To reiterate, the risk hypothesis predicts a significant positive correlation between point-type richness and temperature. It also predicts a significant negative correlation between point-type richness and precipitation. The population size hypothesis predicts a significant positive correlation between point-type richness and population size.

In the second analysis, we created a generalized linear model (GLM) to simultaneously evaluate the relative importance of the proxy variables. Number of point types was designated as the response variable and the environmental risk and population size variables as the predictor variables. We modeled number of point types with a Poisson distribution, which is appropriate for count data. As noted earlier, the risk hypothesis predicts that the global temperature proxy will be positively associated with point-type richness, the regional precipitation proxy will be negatively associated with point-type richness, and both relationships will be independent of the population size proxy. Conversely, the population size hypothesis predicts that the population size proxy will be associated with point-type richness independent of the two risk proxies.

PASW (SPSS) 19 was used to carry out all the analyses.

Results

The bivariate correlation indicated that variation in number of point types through time is uncorrelated with population size ($r=-0.097$, $p=0.837$). In addition, the trend in the data is negative and therefore runs counter to the predictions of the population size hypothesis. The results of the correlation using ranked population size and number of point types through time are qualitatively the same ($r=-0.179$, $p=0.713$). The correlation between the regional proxy for precipitation and the number of point types by time period was not significant ($r=0.463$, $p=0.295$). Lastly, the global proxy for temperature is significantly correlated with the number of point types through time ($r=0.812$, $p=0.027$). The relationship between global temperature and number of point types by time period is positive: As global temperature rises, the number of point types for each time period increases. Thus, the bivariate correlations support the risk hypothesis but do not support the population size hypothesis.

The GLM results were consistent with the results of the bivariate correlations. The population size proxy did not have a significant effect on point richness, and the slope was negative (Fig. 1a). The regional proxy for precipitation also did not have a significant effect (Fig. 1b). In contrast, the global environmental proxy for temperature showed the only significant effect in the model (Fig. 1c; Table 2). Thus, GLM analysis also supported only the risk hypothesis.

Discussion and conclusions

The bivariate correlation and GLM analyses indicate that temporal changes in point-type richness in Texas are significantly associated with changes in one of our proxies of risk—global temperature. The second proxy variable for environmental risk, precipitation estimates derived from a regional sedimentary record of stable carbon isotopic change, showed no correlation with the number of point types. We also found no relationship between changes in point-type richness and changes in population size. Thus, overall, the results are consistent with the risk hypothesis and inconsistent with the population size hypothesis.

There are two possible explanations for the inconsistency between the results obtained from the global temperature data and those obtained from the regional precipitation data. The first is that the regional environmental proxy that we used—stable isotopes from the Aubrey site—does not capture changes in precipitation that reflect broad changes across Texas. The second is that precipitation may not be selectively important. Evidence from other palaeoenvironmental records suggests that the former possibility is likely correct. Most palaeoenvironmental studies in Texas fit better impressionistically with the global temperature record than with the regional precipitation record that we used (e.g., Bousman 1998; Holliday 1989, 2001; Nordt et al. 1994; Toomey et al. 1993). This suggests that the Aubrey stable-isotope record is likely subject to local microenvironmental effects and therefore, contrary to what we assumed, does not reflect climatic changes across Texas.

A further issue that might be raised with regard to our results is that our data on point types mixes some types potentially used by farming groups with those used by hunter-gatherers. Archaeological evidence suggests that some farming was carried out in Texas during the Late Prehistoric period (Johnson and Hard 2008),

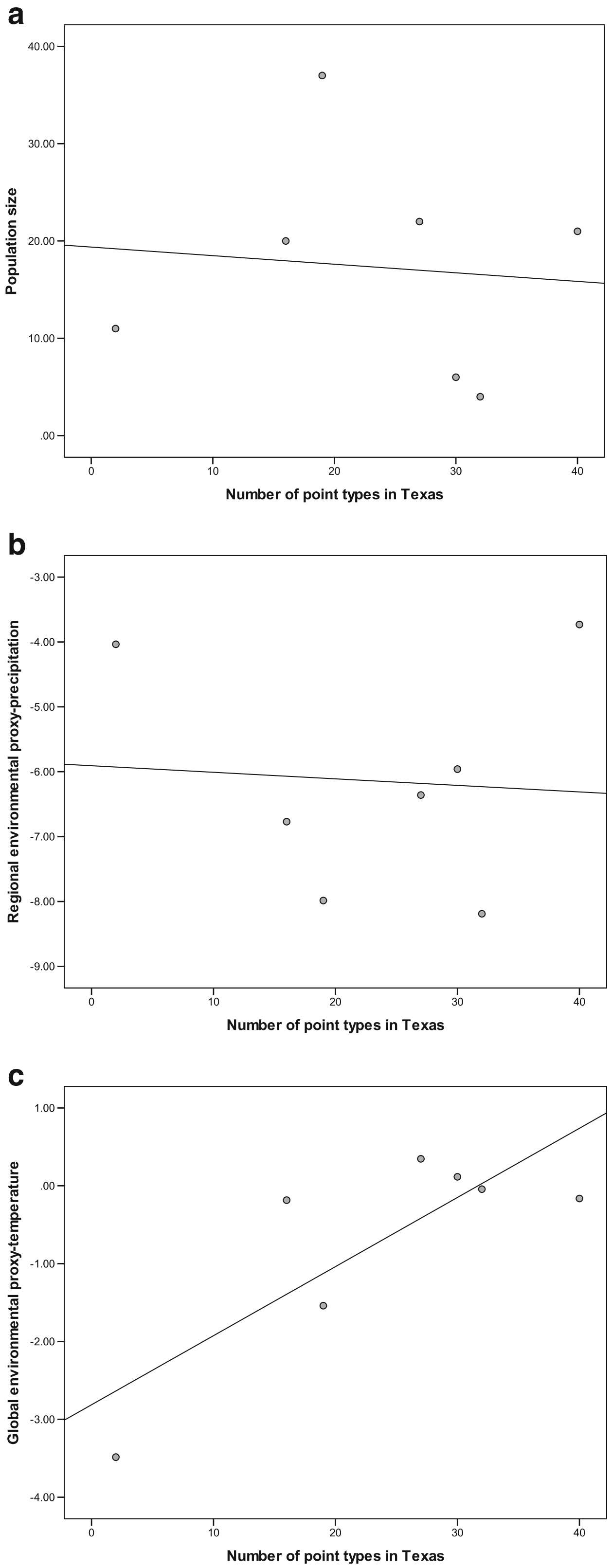

Fig. 1 Scatter plots of the relationships between the number of point types in Texas by time period and the predictor variables. **a** Number of points vs population size proxy. **b** Number of points vs regional environmental risk proxy (precipitation). **c** Number of points vs global environmental risk proxy (temperature)

although it is difficult to determine which types farmers might have used. The problem with including point types used by farmers is that previous studies suggest that different processes may be governing the production of richness in toolkits used by farmers (e.g., Collard et al. 2013c; Kline and Boyd 2010). Given this, we removed the potential confounding factor of Late Prehistoric farmers from our dataset and ran the statistical analyses again to assess the impact of farming on our results. The resulting bivariate correlations among the number of point types by time period excluding the Late Prehistoric and the proxies for the competing hypotheses are qualitatively similar to the original results, but the relationships are strengthened. The number of point types by time period remains uncorrelated with population size (r=–0.222, p=0.673), and the regional environmental risk proxy for precipitation (r=–0.652, p=0.161), together with the number of point types by time period, is still significantly correlated with the global environmental risk proxy for temperature (r=0.882, p=0.020). The GLM excluding the Late Prehistoric time period showed no relationship with population size, a significant negative relationship with precipitation, and a significant positive relationship with temperature (Table 3). It is interesting that the results of the GLM without types used by farmers show a significant negative relationship between the regional proxy and point-type richness. This result differs from the nonsignificant relationship resulting from the full set of data, suggesting that the Late Prehistoric was the period most affected by the local microclimate around the Aubrey site, as noted above. In fact, the regional precipitation data show that the Late Prehistoric period was the driest period, whereas it was only the fourth-warmest period. Thus, both sets of results excluding point types that were made by a combination of Late Prehistoric farmers and hunter-gatherers indicate stronger relationships between environmental risk and point-type richness.

Although our analyses are consistent with the environmental risk hypothesis, another possible explanation is that it is simply environmental change rather than risk that is driving technological richness. The former hypothesis suggests that risk of resource failure drives the creation of specialized tools. In other words, the mismatch between the available toolkit and the adaptive problems presented by a risky environment compels a tool user to bear the costs of innovating and keeping a richer and more complex toolkit. The latter hypothesis is broader and suggests that any environmental change, whether it be to a more or less risky environment, decreases the benefits of socially learned technology and increases the benefit of trial-and-error experimentation with existing tools (Boyd and Richerson 1985). This is

Table 2 Results of the generalized linear model with the number of types in Texas by time period as the response variable and the environmental risk and population size variables as predictors

Parameter	*B*	Std. error	95 % Wald lower CI	95 % Wald upper CI	Wald chi-square	Significance
(Intercept)	3.561	0.3760	2.824	4.298	89.705	0.000
Population size proxy	0.004	0.0085	–0.012	0.021	0.276	0.599
Regional risk proxy (precipitation)	0.042	0.0528	–0.062	0.145	0.626	0.429
Global risk proxy (temperature)	0.512	0.1062	0.304	0.720	23.221	0.000

because environmental change produces a mismatch between the technology that is cheap to learn by means of social transmission and the new environmental conditions for which these tools are adapted. Although it is difficult to discriminate between these two hypotheses given the scale of our analyses, we ran an additional correlation between the magnitude of temperature change in the global proxy and the difference in the number of types between periods. The results of this supplementary analysis suggest that it is not the magnitude of environmental change that is driving the point-type richness ($r=0.399$; $p=0.433$) but rather the riskiness of the environment, in this case, increasing aridity.

The results of our study are consistent with those of several studies that have tested the risk and population size hypotheses using ethnohistorical data on hunter-gatherer toolkits. To reiterate, these studies have found that risk is the primary driver of toolkit richness and complexity (Collard et al. 2005, 2013b; Henrich 2006; Read 2006). Our results provide an additional line of evidence that hunter-gatherers react to environmental risk by increasing the number of technological innovations in their toolkit—a finding that is consistent with the argument of Torrence (1989) that more-specialized, and therefore more-complex, tools reduce risk of resource failure.

Our study also has implications for the study of archaeological tools, as it potentially provides a general explanation for the creation of variation in the number of stone-tool types through time and across space. Bifacial stone points used as weapon tips are nearly ubiquitous throughout the entire spatial and temporal distribution of human occupations in North America. Archaeologists have devoted considerable effort to constructing typological schemes to classify the wide array of bifacial points in the archaeological record. Rarely, however, have archaeologists investigated the cause, or causes, that drive the changes that result in the diversification of point forms into different types at the scale addressed here. The research that has been done has focused on proximate explanations that usually invoke modifications, such as those noted in different hafting arrangements (e.g., Musil 1988) or in the innovation and spread of new weapon delivery systems such as the bow and arrow (e.g., Bingham et al. 2013; Lyman et al. 2008, 2009). These proximate explanations are important, but they do not provide an ultimate explanation for the variation. The results of our study suggest that environmental risk—specifically, increasing temperature—is driving innovations and adoptions in points and, as a result, the subsequent diversification of points into new "types."

The obvious next step is to investigate archaeological farming groups to determine if risk or population size drives technological innovations in the toolkits used by farmers over a long period of time. Our expectation, based on previous ethnographic studies (Collard et al. 2013c; Kline and Boyd 2010), is that population size will be the driver of technological richness and complexity. The difficulty will be to find long temporal sequences of farming populations in the archaeological record to test this hypothesis. The Near East and Central Mexico are the two most obvious places to begin, as both areas used domesticated plants for several thousands of years (Larson et al. 2014).

Table 3 Results of the generalized linear model with the number of types in Texas by time period, excluding the Late Prehistoric period, as the response variable and the risk and population size variables as predictors

Parameter	*B*	Std. error	95 % Wald lower CI	95 % Wald upper CI	Wald chi-square	Significance
(Intercept)	1.959	0.6411	0.702	3.215	9.335	0.002
Population size proxy	–0.001	0.0089	–0.019	0.016	0.023	0.878
Regional risk proxy (precipitation)	–0.192	0.0889	–0.367	–0.018	4.686	0.030
Global risk proxy (temperature)	0.463	0.1296	0.209	0.717	12.753	0.000

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