

Research paper

Middle-Holocene climates and human population densities in the Great Basin, western USA

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Abstract

Much of western North America saw higher temperatures and lower precipitation during the middle Holocene. The Great Basin became much drier and warmer than it is today, causing major shifts in lake levels, treelines, plant community composition, and vertebrate distributions and abundances. To assess the impact of climate change on middle-Holocene human population densities in this region, we examine the frequency structures of radiocarbon-dated archaeological sites through time in three separate parts of the Great Basin: the Bonneville Basin, Fort Rock Basin, and western Lahontan Basin. The results of the analysis support the hypothesis that human population densities in many parts of the Great Basin dropped substantially in response to middle-Holocene climate change but also document that there were intervals during the middle Holocene in all three areas that appear to have been marked by temporary population increases. We hypothesize that these increases were associated with equally temporary increases in effective precipitation but, lacking adequate paleoenvironmental data, do not attempt to test this hypothesis.

Keywords

climate change, Great Basin, human population density, middle Holocene, paleoenvironments, summed probability distributions

Introduction

The Great Basin, the area of internal drainage in the western USA (Figure 1), is today marked by hot summers, cool winters, dramatic elevational relief, and low elevation areas in which evaporation exceeds, and at times greatly exceeds, precipitation. As challenging as modern environmental conditions can be in the Great Basin today, however, they are benign compared to the climates that marked this area during the middle Holocene.

During the early Holocene, the Great Basin was generally far cooler and moister than it is now. Lakes and marshes existed in valleys that are now dry, sagebrush (*Artemisia tridentata*) thrived in low-elevation settings that are currently dominated by plants adapted to far more arid and saline contexts, and small mammals that are today confined to higher elevations or more northerly settings existed in areas that are now much too xeric to support them.

All of this changed during the middle Holocene, a period that saw profound environmental changes driven by reduced effective precipitation throughout this region. Many of the early-Holocene lakes and marshes desiccated and those lakes that endured shallowed significantly. In the Lake Tahoe Basin on the Nevada–California border, for instance, trees grew in areas that are now 4 m beneath the surface of Lake Tahoe itself, and Pyramid Lake, which is in part fed by waters flowing from Lake Tahoe, fell dramatically (Benson *et al.*, 2002; Harding, 1965; Lindström, 1990, 1996; Mensing *et al.*, 2004). At least the middle reaches of the Humboldt River, one of the major waterways of the northern Great Basin, dried, as did Humboldt Lake, today the recipient of the waters carried by the Humboldt River (Byrne *et al.*, 1979; Miller *et al.*, 2004). Bristlecone pine treelines on the White

Mountains of southeastern California moved some 80 to 150 m upslope (LaMarche, 1973), and moisture-dependent small mammals were extirpated from a diverse variety of low-elevation settings (Grayson, 2000, 2006). The Blue Lake wetlands, in Utah's western Bonneville Basin, seem to have desiccated during the heart of the middle Holocene (Louderback and Rhode, 2009); just to the south, the wetlands associated with Mosquito Willie's spring vanished (Kiahtipes, 2009).

The onset of middle-Holocene climatic conditions in the Great Basin is time-transgressive, with different places showing the effects of decreased precipitation/evaporation ratios at different times. In general, however, the period between about 8300 and 4500 ¹⁴C yr BP was marked by the greatest aridity the Great Basin has seen during the last 10 000 years, and perhaps for the last 100 000 years or more (all dates in this paper are in radiocarbon years unless otherwise indicated).

It was Ernst Antevs who first proposed, some 60 years ago, that the middle Holocene in the arid west, including the Great Basin, was markedly hot and dry (Antevs, 1948). He referred to this period as the 'Altithermal', a term that remains in occasional use. The dates he assigned to this period were derived from correlations

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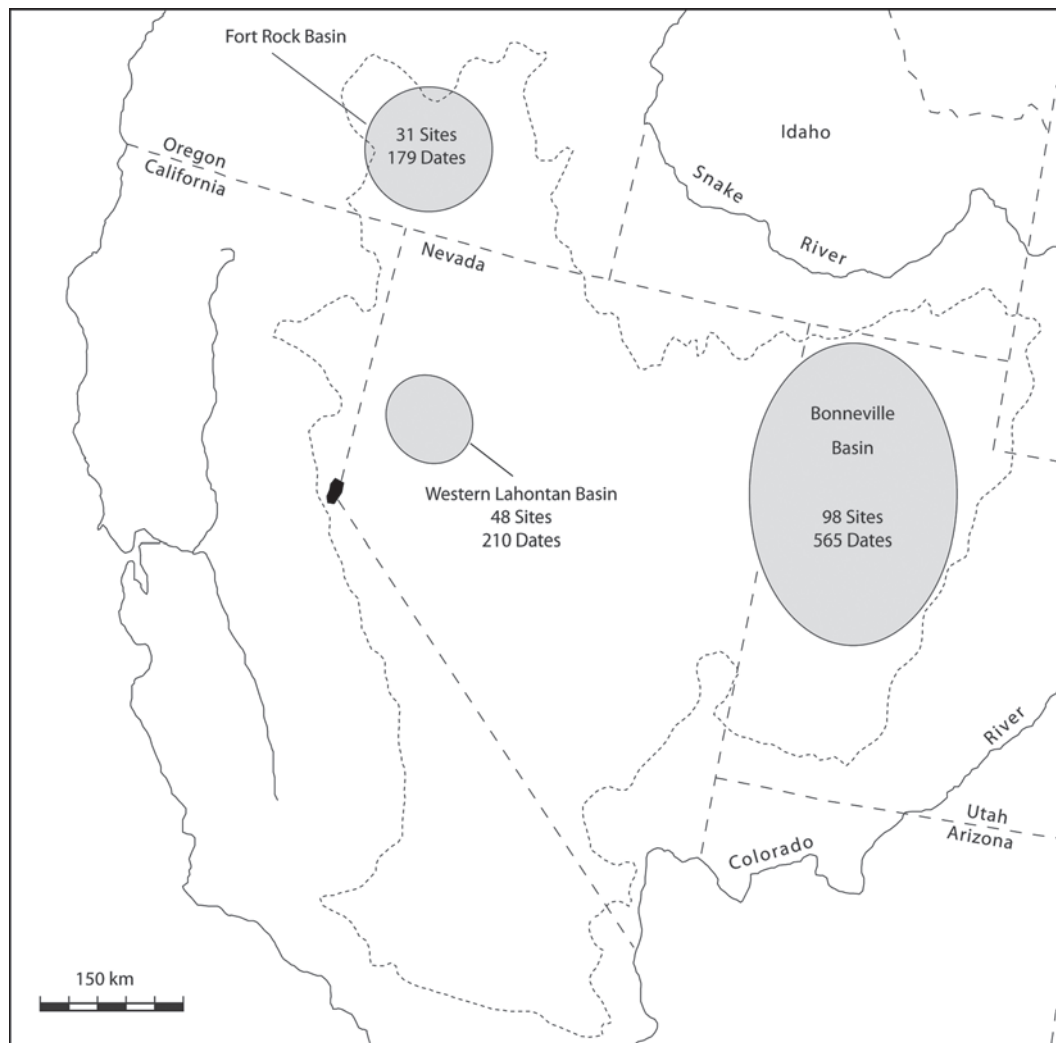


Figure 1. The Great Basin (dotted line), with regions discussed in the text

with the Swedish varve chronology and changed slightly over the years. Generally, he placed the Altithermal at 7500–4500 cal. yr BP, quite similar to current middle-Holocene chronologies. Indeed, although we now know that the middle Holocene in the Great Basin saw significant climatic fluctuations and was not as monolithically hot and dry as Antevs thought – the ‘Great Drought’ he called it – his inferences about the nature and chronology of middle-Holocene climate in this region were astonishingly accurate.

At the same time as Antevs defined the Altithermal, he also suggested that human populations in the Great Basin declined dramatically, with people moving ‘to mountain valleys and to the centers of basins with water’ (Antevs, 1948: 183). Many others have agreed with this suggestion, both in general and for particular parts of the Great Basin (e.g. Aikens and Madsen, 1986; Baumhoff and Heizer, 1965; Benson *et al.*, 2002; Fagan, 1974; Grayson, 1993; Kelly, 1997; Mehringer and Cannon, 1994; Sutton *et al.*, 2007). However, it has also been postulated that Great Basin populations grew arithmetically through time, with no climate-related population fluctuations (Madsen, 2002). While there have been attempts to examine changing population densities through time in particular regions in the Great Basin by using radiocarbon dates or other time-sensitive markers (e.g. Grayson, 1993 in the Fort Rock Basin, Benson *et al.*, 2002 in the western Lahontan Basin, and Madsen, 2002 in the Bonneville Basin), there have been no broad-scale

attempts to examine this issue using comprehensive radiocarbon data bases. We provide that attempt here.

Methods

We employ a broad sample of archaeological sites with radiocarbon dates from three distinct regions within the Great Basin to assess the degree to which population minima were, in fact, reached during the middle Holocene. Archaeological sites in our data base vary in their elevation and position on the landscape, but all are from the Bonneville Basin of western Utah, the Fort Rock Basin of south-central Oregon and the western Lahontan Basin (the Pyramid, Winnemucca, Humboldt, and Carson basins) of western Nevada (Figure 1). The boundaries that define these basins are based on the former extent of the pluvial lake systems in each area. These regions were chosen because each has been the focus of detailed, published archaeological research covering the entire Holocene and each has a substantial corpus of radiocarbon dates.

To build the radiocarbon data bases on which our analysis depends, we conducted a thorough literature search and contacted individual investigators to assure that our date compilations were as complete as we could make them. In all instances, we incorporated into the data base only radiocarbon ages whose association with cultural material could be adequately assessed. In all

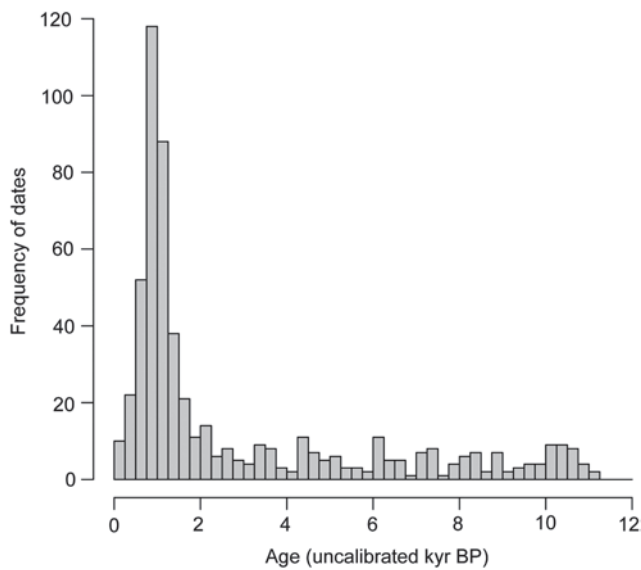


Figure 2. Histogram of radiocarbon date frequencies for archaeological sites in the Bonneville Basin including Fremont. Interval size is 250 years

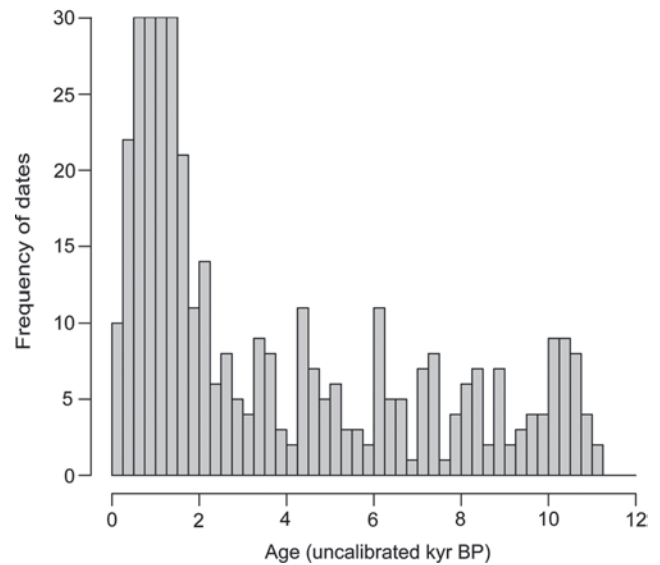


Figure 3. Histogram of radiocarbon date frequencies for archaeological sites in the Bonneville Basin truncated at 30. Interval size is 250 years

instances, we rejected dates that had been rejected by the original analysts, dates from stratigraphically disturbed settings, dates lacking proper pretreatment (e.g. Taylor, 1987), dates on bulk sediments, and dates whose tight association with cultural material could not be established. This procedure provided us with 565 radiocarbon dates from 98 archaeological sites within the Bonneville Basin, 179 dates from 31 archaeological sites from the Fort Rock Basin, and 210 radiocarbon dates from 48 sites within the western Lahontan Basin (data available from LAL on request).

Results

Histograms for dated material

The resultant radiocarbon dates were organized into histograms with interval sizes of 250 years (Figures 2–5). This particular interval size was chosen empirically because it most sensitively reflects the peaks and troughs in the data for all three regions.

Between about 1350 and 600 ¹⁴C yr BP, the edges of the Bonneville Basin saw the development of a cultural phenomenon known as the Fremont, marked by often substantial village sites and diets that were variably dependent on maize horticulture. Fremont archaeology has been the intense focus of archaeological research for many decades, some of which has generated large numbers of radiocarbon dates. As a result, the sheer number of dated Fremont sites overwhelms trends otherwise evident within earlier time periods. Because of this effect, we have provided two versions of the Bonneville Basin histogram. The first (Figure 2) includes all radiocarbon dates for this region. The second version (Figure 3) truncates the number of Fremont dates at 30 so earlier trends may be more readily seen.

Summed probability curves for dated material

The summed probability curves we use here are a logical extension of kernel density estimates (KDEs; see Baxter *et al.*, 1997) as applied to the derivation of radiocarbon chronologies (e.g.

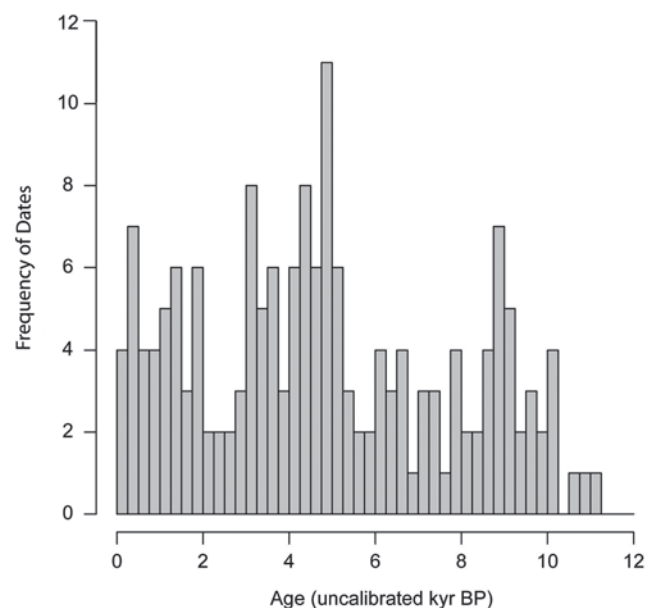


Figure 4. Histogram of radiocarbon date frequencies for archaeological sites in the Fort Rock Basin. Interval size is 250 years

Gajewski *et al.*, 2006). In the KDE approach, an uncalibrated ¹⁴C date is represented by a probability distribution, or kernel. To calculate a KDE for a set of dates, a probability curve is centered at each date by using the mean value for that curve, with the same standard deviation used for all curves. To calculate a probability for any location on the graph, the probability of each curve at that point is summed and then normalized by the number of data points. The summed probability curves that we employ here proceed in the same fashion, except that rather than using a fixed standard deviation, we use the standard error associated with each ¹⁴C date. Summed probability distributions are then generated by adding together each of the probability distributions provided by the individual dates used in our analyses.

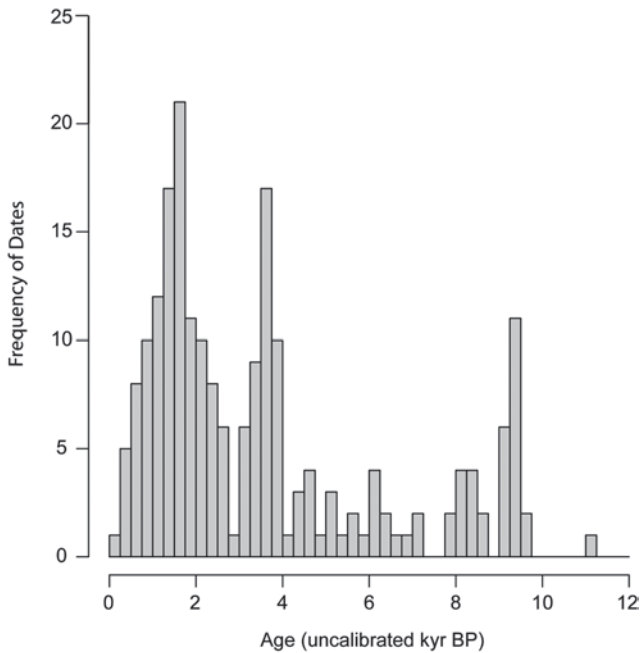


Figure 5. Histogram of radiocarbon date frequencies for archaeological sites in the western Lahontan Basin. Interval size is 250 years

The ticks on the x-axis of the resultant graphs show the location of the means of the original ^{14}C curves. We constructed summed probability curves for each of our three regions (Bonneville, Fort Rock, and western Lahontan basins) separately, as well as for all regions together (Figures 6–9). For the Bonneville Basin (Figure 6) and the composite curve (Figure 9), we exclude dates for the past 1500 years to eliminate the overwhelming influence of the dates available for the Fremont phenomenon (see above).

Interpretation of temporal curves

As many have observed, the interpretation of temporal frequency curves in archaeology is not necessarily straightforward (e.g. Berry, 1982; Buchanan *et al.*, 2008; Kuzmin and Keates, 2005; Neme and Gil, 2009; Rick, 1987; Riede, 2009). For instance, low-density but highly mobile human foragers may create large numbers of archaeological sites which, if subsequently discovered and radiocarbon-dated, may create the impression of greater numbers of people on the landscape than actually existed. Differential visibility of archaeological sites and research interests can have similar effects, as with the Fremont example discussed earlier. Another example is provided by Late Pleistocene and early-Holocene archaeological sites in the Great Basin. The great majority of these have been difficult to date because they reside on the surface (e.g. Beck and Jones, 2009). When buried deposits of this age have been found, their importance has led them to be the subject of intense radiocarbon dating programs. As a result, greater numbers of dates have been generated for them than would likely have been the case for more recent deposits (e.g. Graf, 2007).

In addition, Surovell and Brantingham (2007) and Surovell *et al.* (2009) have observed that temporal frequency distributions of archaeological dates may record taphonomic processes more than they reflect changing human population numbers. They correctly argue that such destructive processes as erosion and the decay of organic material preferentially lead to the destruction of

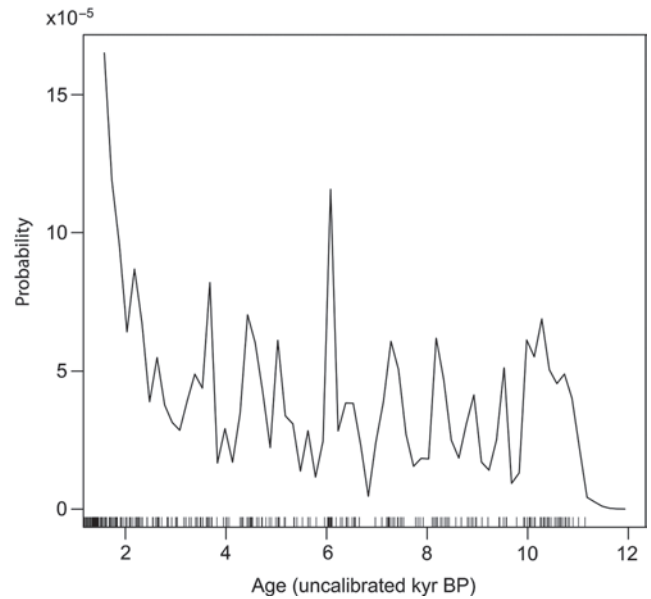


Figure 6. Summed probability curve for radiocarbon date frequencies in the Bonneville Basin. Fremont dates are not included. Interval size is 150 years

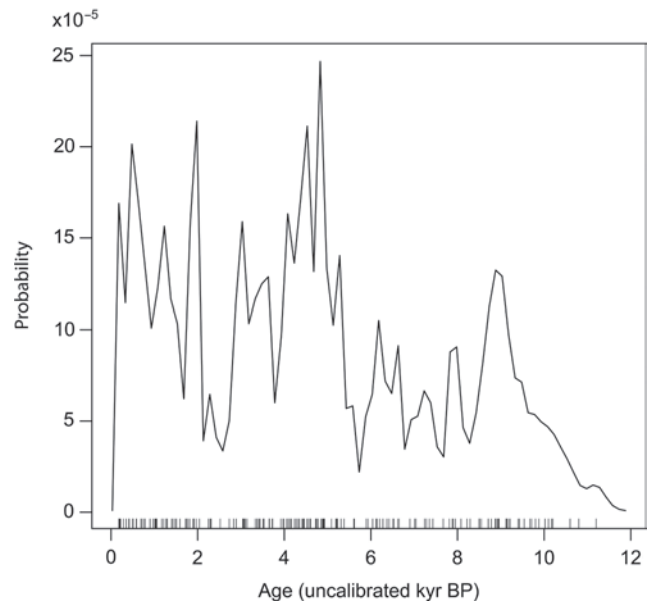


Figure 7. Summed probability curve for radiocarbon date frequencies in the Fort Rock Basin. Interval size is 150 years

older material, creating a taphonomic bias toward the preservation of recent archaeological events.

All of these biases are very real, but there exist no other ways to examine possible human population density responses to the challenges posed by middle-Holocene environments in the Great Basin. We present our results as a test of the 60-year-old hypothesis that human population numbers declined in the Great Basin during this interval. We do not assume that there is a linear relationship between numbers of radiocarbon dates from archaeological sites and human population numbers, but instead that troughs in date frequencies reflect diminished amounts of archaeological material and, therefore, reflect reduced densities of people on the landscape, and *vice versa*.

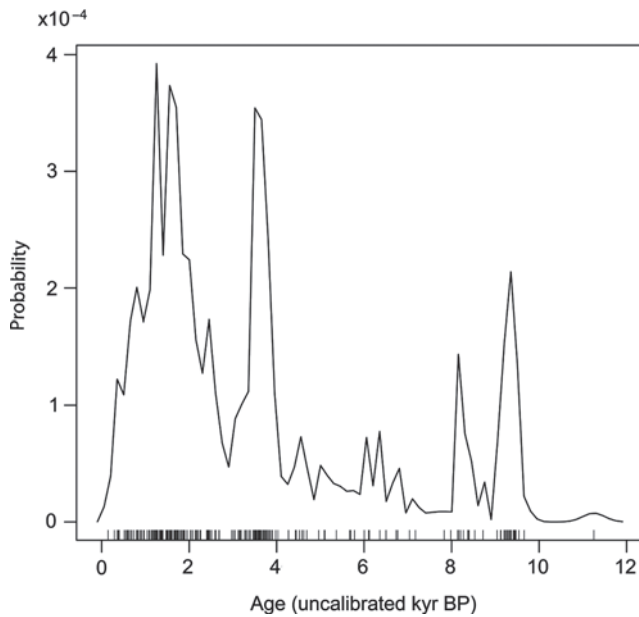


Figure 8. Summed probability curve for radiocarbon date frequencies in the western Lahontan Basin. Interval size is 150 years

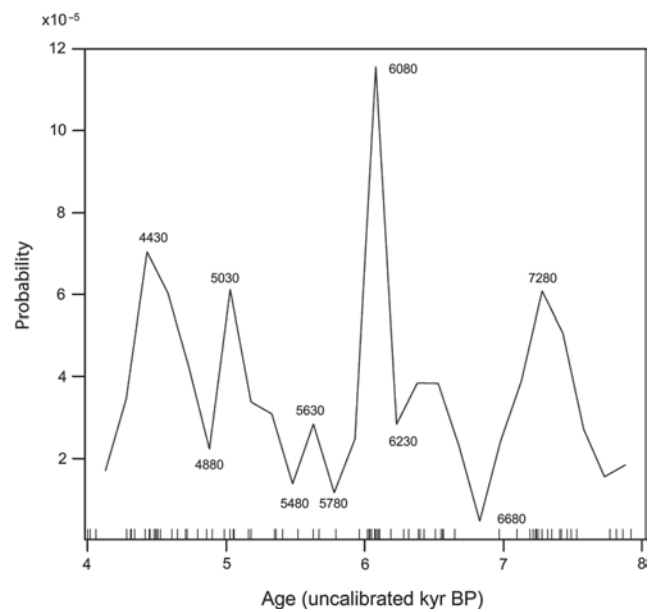


Figure 10. Summed probability curve for middle Holocene (4000–8000 ¹⁴C yr BP) radiocarbon dates in the Bonneville Basin. The age of each peak and trough, in radiocarbon years, is indicated. Interval size is 150 years

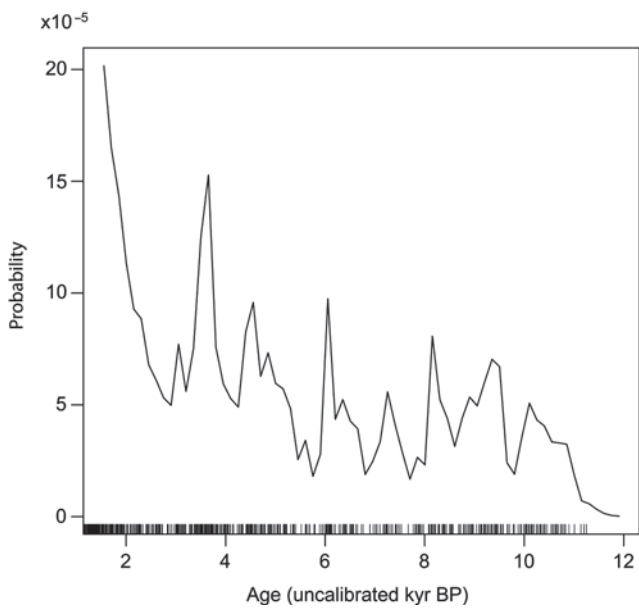


Figure 9. Summed probability curve for radiocarbon date frequencies for all regions. Fremont dates are not included. Interval size is 150 years

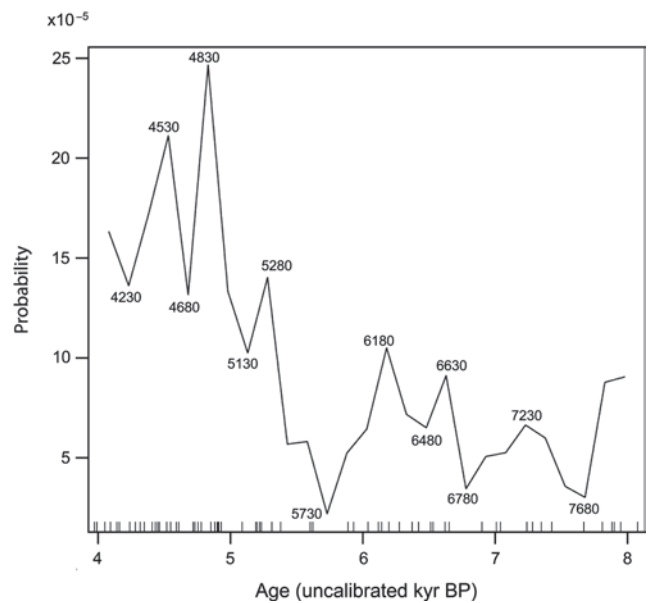


Figure 11. Summed probability curve for middle Holocene (4000–8000 ¹⁴C yr BP) radiocarbon dates in the Fort Rock Basin. The age of each peak and trough, in radiocarbon years, is indicated. Interval size is 150 years

Results

In all three of the areas that we have examined, either the lowest frequency (Bonneville and Fort Rock basins) or lowest sustained frequencies (western Lahontan Basin) of radiocarbon dates occur during the middle Holocene, a pattern that is also evident in the composite curve for all three areas combined (Figures 6–9). Figures 10–13 present the middle-Holocene sections of these curves; Table 1 summarizes the chronological placement of the peaks and troughs shown by the figures.

We used the same data to generate a series of Gaussian kernel density estimates, each using a different fixed standard deviation

(50, 100, and 250 years), for all three areas. While the results differ in detail, they show the same patterns provided by the cumulative probability curves (e.g. Figures 14 and 15).

These results support the hypothesis that the Great Basin saw a decrease in human population densities during the middle Holocene. Our data suggest that this response was weakest in the Bonneville Basin (Figures 3, 6, 10 and 14). As a result, it is not surprising that those who have argued that Great Basin human populations did not decline during the middle Holocene have worked in precisely this area (e.g., Aikens, 1970; Madsen, 2002).

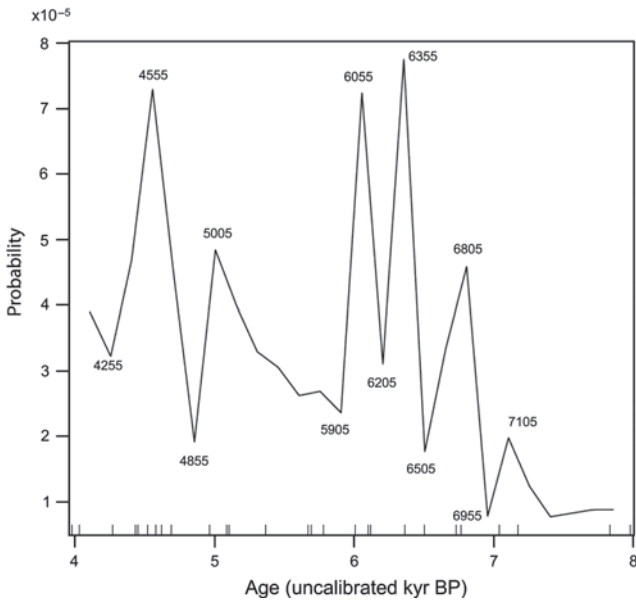


Figure 12. Summed probability curve for middle Holocene (4000–8000 ¹⁴C yr BP) radiocarbon dates in the western Lahontan Basin. The age of each peak and trough, in radiocarbon years, is indicated. Interval size is 150 years

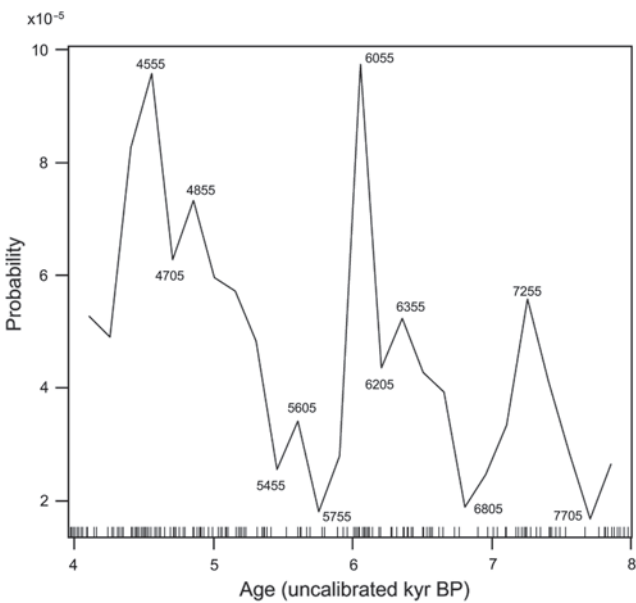


Figure 13. Summed probability curve for middle Holocene (4000–8000 ¹⁴C yr BP) radiocarbon dates in all three regions. A radiocarbon date for each peak and trough is indicated. Interval size is 150 years

We also note that the peaks and troughs of the middle-Holocene frequency curves across regions show little chronological correspondence. We speculate that this asynchronicity across regions reflects the fact that middle-Holocene climate change in the Great Basin was likewise asynchronous (Grayson, 1993, 2010). We return to this issue below.

Our results are unlikely to reflect the kinds of taphonomic processes discussed by Surovell and Brantingham (2007) and Surovell *et al.* (2009) for the simple reason that, in our samples, the probability of occurrence of middle-Holocene dates is less than the

Table 1. Ages of radiocarbon date peaks and troughs in three regions of the Great Basin

Region	¹⁴ C peaks (yr BP)	¹⁴ C troughs (yr BP)
Bonneville Basin (Figure 10)	6080	6680, 5480–5780
Fort Rock Basin (Figure 11)	4830	5730
Western Lahontan Basin (Figure 12)	4555, 6055, 6355	4855, 5905, 6505, 6955
Composite (Figure 13)	4555, 6055	5755, 6805, 7705

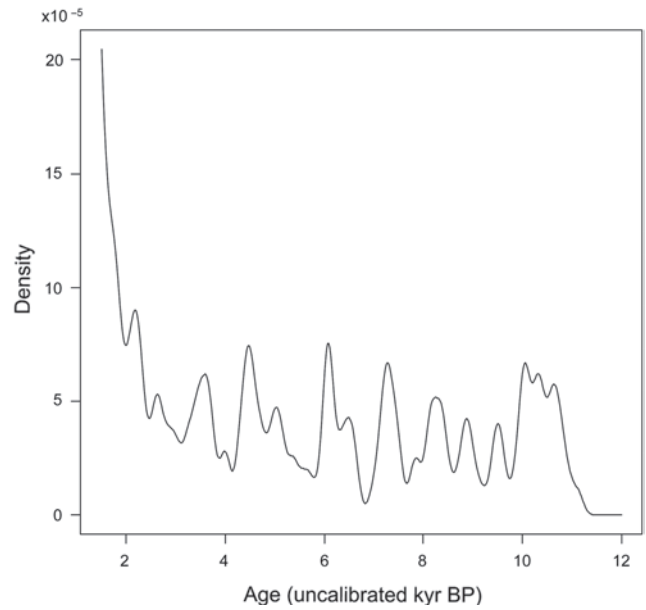


Figure 14. Gaussian kernel density estimate curve for the Bonneville Basin using a fixed standard deviation of 100 years and an interval size of 250 years

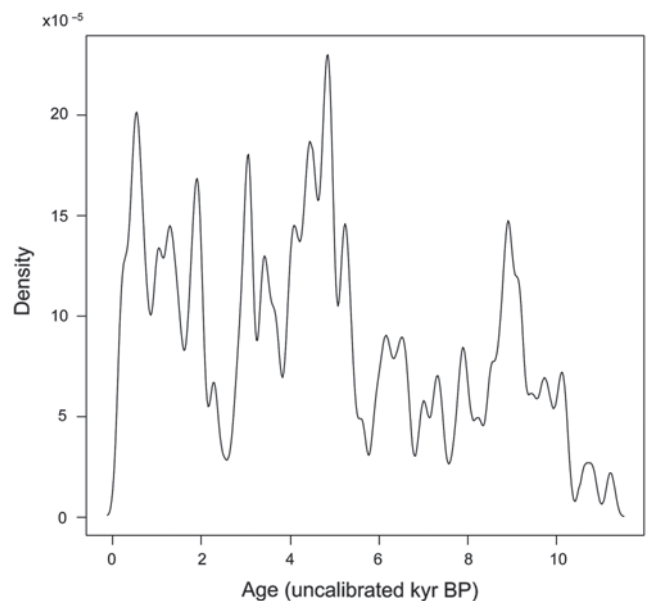


Figure 15. Gaussian kernel density estimate curve for the Fort Rock Basin using a fixed standard deviation of 100 years and an interval size of 250 years

probability of occurrence of earlier ones. The great increase in the number of late-Holocene archaeological dates compared with those that come before may partially reflect taphonomic and/or dating biases, but the steep and saw-toothed nature of those increases suggests that the causes of these patterns must be more complex. We conclude that, just as others have argued before us on the basis of smaller and more localized data sets, human populations densities in the Great Basin during the middle Holocene appear to have been lower than those that came before or after.

Human population density and environmental history

Our results support the hypothesis that, in the areas we have examined, human population densities were lower during the middle Holocene than they were before or after this time-transgressive period. Since, as we have discussed, this interval was also marked by pronounced extremes of aridity, we assume that these generally low population densities were caused by evaporation/precipitation ratios that were, in terms of human lives, highly unfavorable compared with those that came before and after. In support of this assumption, we note that historic Great Basin human population densities were highest in areas that were well-watered, lowest in areas that were not (Steward, 1938; Thomas, 1972).

Antevs, we have noted, treated the Altithermal as if it had been monolithically hot and dry. Today, we know that this roughly 3500 year period was marked by significant episodes of increased and decreased effective precipitation (e.g. Grayson, 2010; Mehringer, 1985, 1986; Mehringer and Cannon, 1994). We have already hypothesized that the distinct middle-Holocene peaks and troughs in the archaeological radiocarbon records for all three regions we have examined might be related to these episodes of altered effective precipitation.

Unfortunately, it does not seem possible to test this hypothesis directly. Our radiocarbon probability curves are constructed from between 179 (Fort Rock Basin) and 565 (Bonneville Basin) radiocarbon dates. The paleoenvironmental record available from these regions, on the other hand, has been built from scattered sequences that have routinely been dated with single, and often widely spaced, radiocarbon dates. Until many more paleoenvironmental sequences are available, comparing the two data sets is unlikely to be productive and we have not pursued this approach here.

Conclusions

For many years, archaeologists and others have suggested that decreased effective precipitation during the middle Holocene caused a significant decline in human population densities in the Great Basin. We have tested this hypothesis by building temporal frequency curves using radiocarbon dates from archaeological sites in three geographically separate areas within this region. In all three instances, the lowest frequencies of known sites occur during the middle Holocene, with the weakest response in the Bonneville Basin. Our analysis represents the first attempt to test this hypothesis using comprehensive sets of radiocarbon dates from multiple, geographically separate areas within the Great Basin. We are hopeful that others will extend this approach to other areas within the Great Basin. The frequency curves we have presented also show that, during the middle Holocene, frequency troughs in those curves are separated by well-defined high-frequency peaks. We hypothesize that these peaks are associated with

temporary mesic interludes during the middle Holocene, but available paleoenvironmental data are inadequate to test this hypothesis.

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