Quaternary International 242 (2011) 570–583

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Multiple lines of evidence for possible Human population decline/settlement reorganization during the early Younger Dryas

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ARTICLE INFO

Article history:
Available online 22 April 2011

ABSTRACT

Three approaches are used to test whether or not human populations across North America were affected by abrupt climate change and/or other environmental factors associated with the onset of the Younger Dryas (YD) cooling episode at ca. 12,900 cal BP. They are: (1) frequency analyses of Paleoindian projectile points from across North America; (2) time series of lithic assemblages from eleven Paleoindian quarry sites in the southeastern United States; and (3) summed probability analyses (SPA) of radiocarbon dates from cultural (human-related) sites across North America and parts of the Old World. The results of each analysis suggest a significant decline and/or reorganization in human population during the early centuries of the YD, varying in extent by region. Archaeological settings formerly heavily utilized, such as stone quarries in the southeastern U.S., appear to have been largely abandoned, while over large areas, a substantial decline occurred in the numbers of diagnostic projectile points and cultural radiocarbon dates. Later in the YD, beginning after about 12,600 cal BP, there was an apparent resurgence in population and/or settlements in many areas, as indicated by increases in projectile points, quarry usage, and human-related radiocarbon ages.

1. Introduction

Considerable interest has emerged about the potential effects of abrupt, large-scale climate change on plant and animal populations as well as humans, in part because of growing concerns about potential impacts of modern global warming. Since the end of the last Glacial Maximum ca. 18,000 cal BP, the most pronounced extended climate perturbation following the onset of rapid deglaciation was the Younger Dryas (YD) cooling episode. This began abruptly at ca. 12,900 cal BP (all dates are in calendar or calibrated years before present or BP, unless otherwise noted) and persisted for about 1300 years. Various hypotheses have been proposed to explain the abrupt cooling reversal at the onset of the YD, including shifts in continental meltwater outflow (Kennett and Shackleton, 1975; Broecker et al., 1989, 2010; Carlson, 2007); outburst flooding (Teller, 1988; Murton, 2010); related changes in thermohaline circulation (Broecker et al., 1989; Alley, 2000); and cosmic impact (Firestone et al., 2007). These hypotheses are the subject of ongoing debate and will not be addressed here. It is well accepted that the onset of the YD led to widespread biotic changes in many parts of the Northern Hemisphere, although specific regional biotic and human responses are not well constrained. Investigations into the YD have led to appreciable recent debate about whether or not a significant decline and/or reorganization in human populations occurred at the onset of the YD ca. 12,900 cal BP (cf., Firestone et al., 2007; Anderson et al., 2008a,b, 2009, 2010; Buchanan et al., 2008; Collard et al., 2008; Meltzer, 2009; Holliday and Meltzer, 2010; Meltzer and Holliday, 2010; Steele, 2010). This paper explores what happened to human populations in North America during the YD using three somewhat interrelated lines of evidence: (1) Paleoindian projectile point frequency data; (2) changes in Paleoindian usage patterns of lithic quarries, and (3) summed probability analyses (SPA) of radiocarbon dates related to human activity. The primary focus of this contribution has been to compile and evaluate data using these approaches to determine whether or not the evidence is consistent with changes in human population at the onset of the YD.

2. Climate and culture change: basic assumptions

An extensive literature documents how changes in climate affect biotic communities and human societies. Climate parameters such

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doi:10.1016/j.quaint.2011.04.020

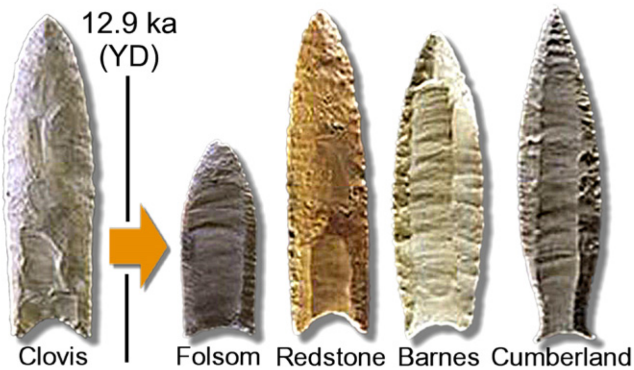

Fig. 1. Clovis (weakly fluted) and immediate post-Clovis (fully fluted/indented based) projectile point forms in North America.

as the type, rate, and magnitude of change help shape the degree of cultural change and may even produce human population bottlenecks. Of particular importance to early human societies was the potential effect of such change on food supplies, and whether this affected the incidence and intensity of epidemics, civil unrest, or warfare (e.g., Fagan, 2000, 2004; Anderson et al., 2007; Rosen, 2007; Zhang et al., 2007). A recent, widespread episode of global cooling of much shorter duration and of lower magnitude than the YD was the Little Ice Age (LIA), lasting from the 1300s until the 1800s A.D. It is widely accepted that the LIA had a significant effect on human populations over broad regions, causing substantial population declines in some areas brought about by crop failure, civil unrest, warfare, and epidemic disease, (e.g., Kremer, 1993; Fagan, 2000; Zhang et al., 2007). The much earlier YD cooling occurred when human populations had not yet made the transition to agricultural food production or developed organizationally large and complex societies, which are presumably more vulnerable to, but also better able to buffer the effects of climate change. Major, abrupt swings in climate have occurred many times since anatomically modern humans emerged ca. 150–200 kyrs BP (e.g., National Research Council, 2002; Labeyrie et al., 2003). Therefore, resolving how the YD might have affected hunting-gathering societies is important towards better understanding earlier episodes of prehistory.

3. Analysis results (1): Clovis and post-Clovis projectile point frequencies in North America

Paleoindian projectile points occur across North America within a number of geographically widespread and variable stylistic horizons (Fig. 1). The 'Clovis horizon' is dated to ca. 13,050 to 12,900 cal BP, just prior to the YD onset, and is marked by classic Clovis points, which typically have flat to weakly indented bases and fluting only partly along the blade (Morrow, 1996; Tankersley, 2004; Waters and Stafford, 2007; Meltzer, 2009). This point style was replaced during the early part of the YD by an assemblage forming a 'full-fluted horizon' and was marked by points with deeply indented bases and long flutes of the Folsom, Gainey, Barnes, Cumberland, and Redstone types. Goodyear (2006, 2010) described these varieties as having been made by 'instrument-assisted' fluting, either by indirect percussion or by direct pressure. These points were in turn replaced by a wide diversity of unfluted forms later in the YD. For the Folsom tradition, radiometric dating and stratigraphic placement are sufficiently well established to show these as post-Clovis, but the temporal range of some of the other full-fluted and unfluted forms is less well documented, and as a result, stratigraphic placement has been inferred based upon stylistic and technological criteria. Although the precise dating and cultural associations of these Paleoindian horizons are incomplete and marked by some overlap, the general projectile point sequence encompassing Clovis, post-Clovis full-fluted, and unfluted forms lanceolate followed by notched forms is accepted by most researchers in eastern North America (e.g., Anderson and Sassaman, 1996; Ellis and Deller, 1997; Bradley et al., 2008;

Table 1
Clovis and immediate post-Clovis assemblages at eleven quarry locations in the southeastern U.S.

Clovis quarries in the Southeastern U.S.						
Site	Site#	St.	Clovis	Post-Clovis	Type of site	References
Carson-Conn-Short	40Bn190	TN	39 Clovis points 540 Preforms 216 Blade cores	5 Cumberland points 10 Unfluted preforms	Quarry, Workshop, Habitation	Norton and Broster, 2008
Wells Creek	40Sw63	TN	18 Clovis points 16 Point Frags 209 Preforms	1 nipple preform?	Workshop, Habitation	Dragoo, 1973, Tune 2010
Sinclair	40Wy111	TN	Clovis points, Preforms, Blades	Redstone, Beaver Lk	Quarry, Workshop	Broster and Norton, 2009
Adams	15Ch90	KY	4 Clovis points 153 Bifaces 555 Blades 140 Cores & Frags.	None	Workshop, Habitation	Sanders, 1990 Gramly and Yahnig, 1991, Yahnig, 2004
Boyd-Ledford	15Ch236	KY	Clovis	Some Cumberland	Quarry, Workshop, Habitation	Freeman et al., 1996, Yahnig, 2004
Roeder	15Ch482	KY	Blade Technology	None	Quarry, Workshop, Habitation	Freeman et al., 1996, Yahnig, 2004
Ezell	15Ch483	KY	Blade Technology 30 Blade Cores	None	Quarry, Workshop, Habitation	Freeman et al., 1996, Yahnig, 2004
Williamson	44Dw1	VA	200 + Clovis points Blades	2 Redstones	Quarry, Workshop, Habitation	McCary, 1951, McAvoy and McAvoy, 2003 Peck, 1985, Hill, 1997
Thunderbird	44Wr11	VA	6 Clovis points Preforms	2 Instrument-assist. pts.	Workshop, Habitation	Gardner, 1974, Johnson, 1996
Topper	38Al23	SC	4 Clovis points 170 Preforms 257 Blades 22 Blade Cores	1 Instrument-assist. pt.	Quarry, Workshop, Habitation	Goodyear and Charles, 1984, Goodyear and Steffy, 2003, Goodyear et al., 2007 Smallwood, 2010; Sain, 2010
Big Pine Tree	38Al143	SC	2 Clovis points Preforms, Blades	None	Workshop, Habitation	Goodyear, 1999

Fig. 2. PIDBA main page at http://pidba.utk.edu/ (Anderson et al., 2010).

Meltzer, 2009; Anderson et al., 2010). Unfortunately, confirming these sequences and precisely dating specific artifact types has been frustrated in the southeast by a scarcity of stratified, well-dated and thoroughly reported archaeological sites spanning the late Pleistocene, particularly from the millennium or two prior to Clovis through the end of the YD and into the early centuries of the Holocene. Where present, such sites have typically not produced large assemblages, as at Page Ladson in Florida (Webb, 2006), or have equivocal associations (Tankersley et al., 2009). On the margins of the region, sites that are extensively dated have been found and reported, including Big Eddy in Missouri (Lopinot et al., 1998, 2000), Gault and Debra L. Friedkin in Texas (Collins and Bradley, 2008; Waters et al., 2011), and Cactus Hill in Virginia (McAvoy and McAvoy, 1997), but comparable sites have yet to be found and thoroughly reported in the lower southeast, a problem long noted (Anderson et al., 1996, 2004; Goodyear, 1999; Anderson, 2005). While sites yielding single component assemblages dating to either the earlier Clovis or later Paleoindian terminal YD Dalton cultures have been reported from the region (e.g., Morse et al., 1996; Morse, 1997; see Table 1, herein), well-dated sites from the intervening period, during roughly the first half of the YD, are rare in the region. For this reason, surface assemblage data remains the principal means employed here to infer relative intensity of occupation over time.

The Paleoindian Database of the Americas (PIDBA), available online (Fig. 2, http://pidba.utk.edu), integrates database and GIS technology to provide location data for almost 30,000 Paleoindian projectile points, measurement and other qualitative attribute data

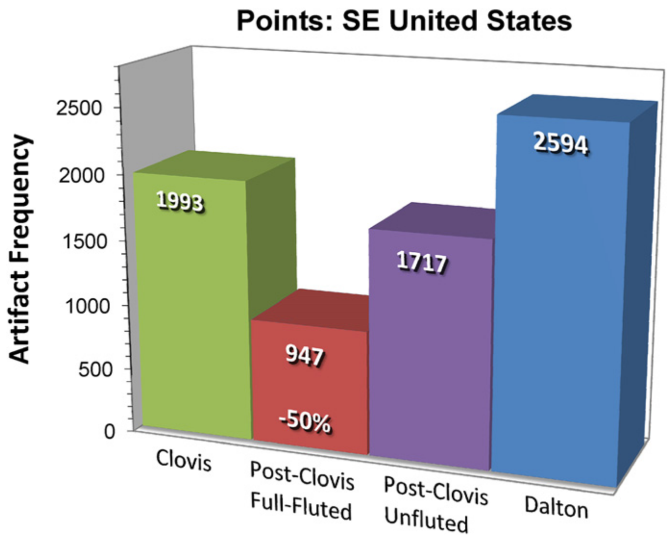

Fig. 3. Graph showing number of points of each style from Clovis to Dalton found in the southeastern U.S. There is an apparent ~50% drop in point totals immediately following Clovis, followed by a rebound in projectile point totals.

on more than 15,000 points, and provides photographs and/or line drawings for nearly 10,000 Paleoindian points from across North America (Anderson et al., 2005, 2010). These data clearly indicate a major decrease in the number of artifacts in many parts of North America during the early centuries of the YD. This decrease is interpreted to represent a decline in human populations and/or a major reorganization of settlement systems, something likely related to the major changes in biota observed over this same general interval. In the southeastern U.S., this decline is particularly dramatic, amounting to a drop of ~50% (Fig. 3). The pattern of immediate post-Clovis decline in eastern North America is also similar in the central part of the continent in an area defined by twenty-one states and provinces in the Great Basin, Rocky Mountains, and Great Plains. Folsom and other related Midland and Sedgwick types ($n = 2527$) display a decline of ~37% relative to the previous Clovis and presumably related fluted forms ($n = 4020$) (Figs. 4 and 5). However, coverage and classification of western projectile point data in PIDBA is less complete than it is in the Southeast, primarily because proportionally fewer local researchers contribute their data to PIDBA, or active data recording projects are not underway, requiring more reliance on published information about artifact counts, which is incomplete for many states or provinces. Additionally, the Clovis category is questionable in some areas, because a generic 'fluted' category is often employed to encompass Clovis forms in addition to non-Folsom, post-Clovis fluted types. Wherever possible, an attempt was made to differentiate these later types from the 'fluted' category, but this has not yet been carried out for the Far West, Northeast and upper Midwest/Canada, where an undetermined number of reported fluted points likely postdate Clovis (e.g., Ellis and Deller, 1997; Morrow and Morrow, 2003; Ives, 2006; Bradley et al., 2008; Meltzer, 2009; Rondo, 2009; Anderson et al., 2010; Prasciunas, 2011).

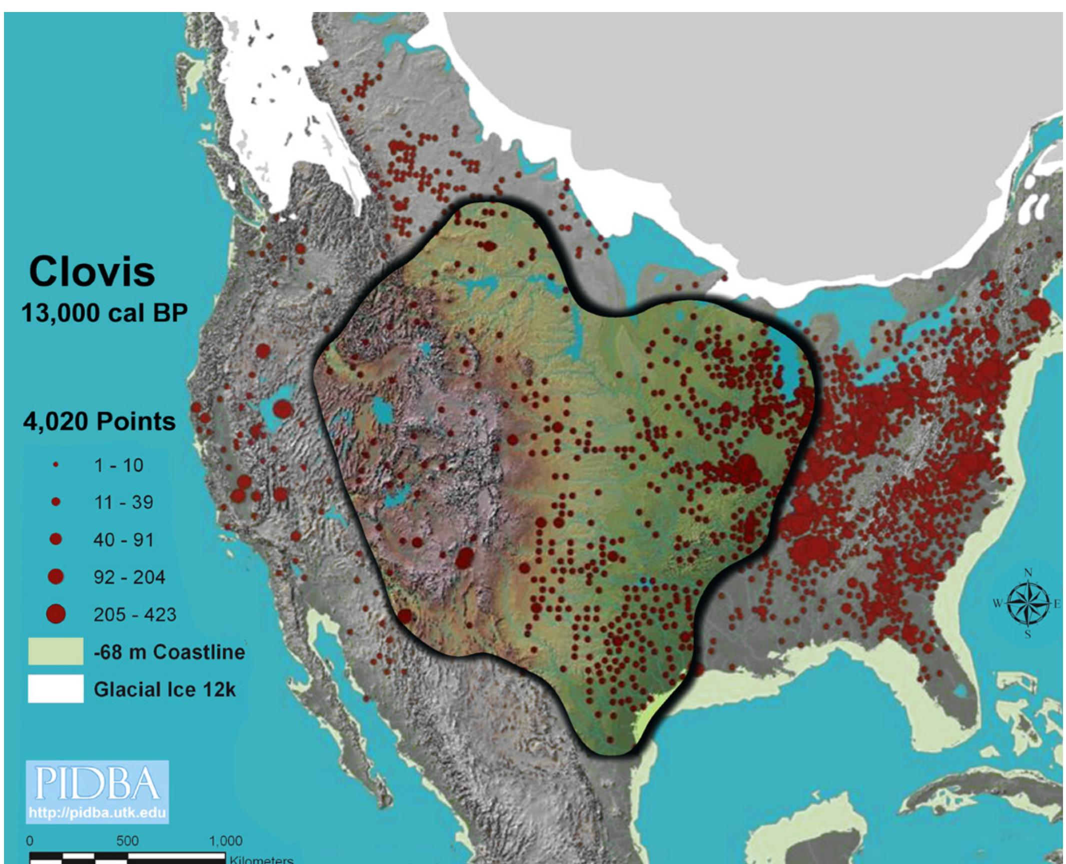

Fig. 4. Clovis and fluted points (excluding Folsom) in the central United States. The dark outline encompasses the twenty-one states and provinces listed in Table 3. Note the visually greater abundance of these points than Folsom points in the same region, as shown in Fig. 5. While it is possible that many fluted points in the Northeast, upper Midwest, in the Ice Free Corridor, and in the Far West are later than Clovis in age, over the geographic sample in question, a clear decrease from Clovis/fluted to Folsom forms is documented.

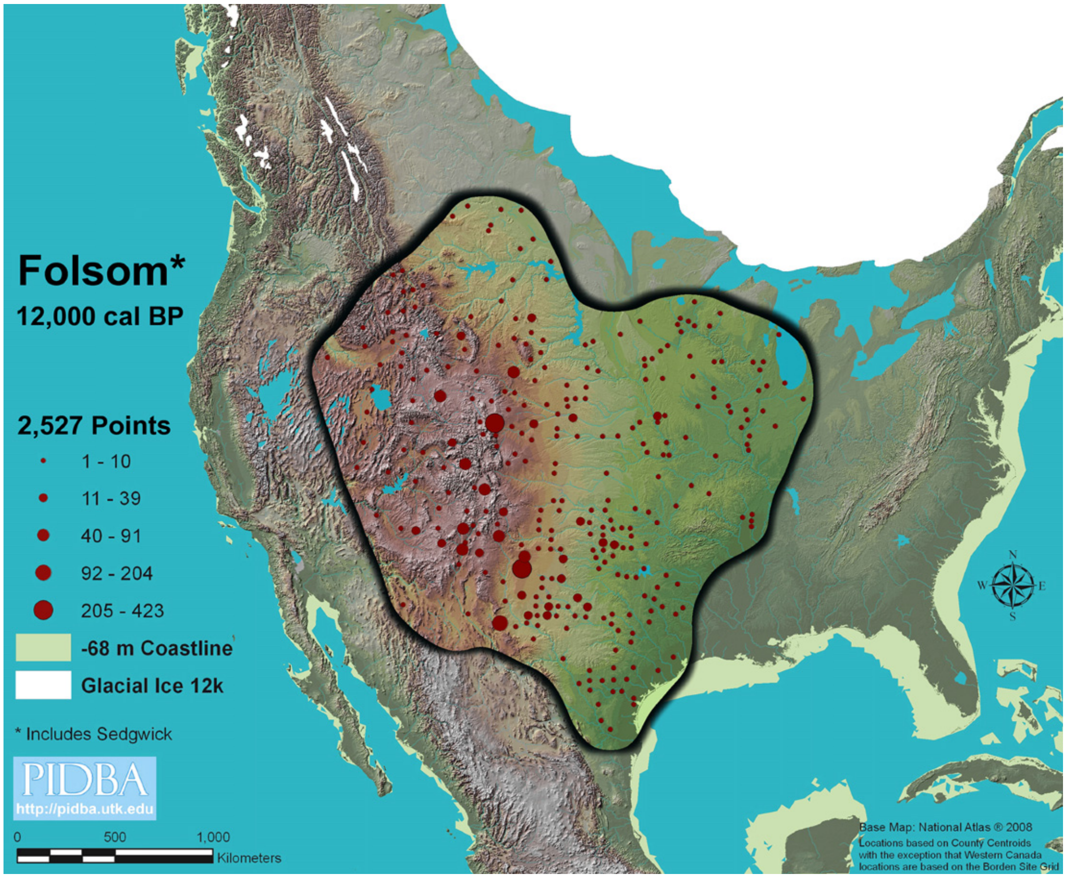

Fig. 5. Folsom point distributions in the central United States. The dark outline encompasses the twenty-one states and provinces listed in Table 3. A clear reduction in numbers is evident when the distribution is compared to Clovis/fluted point incidence in the same region (Fig. 4).

The PIDBA Project represents a work in progress with numerous acknowledged sources of bias (Anderson and Faught, 1998; Shott, 2002; Anderson, 2010; Anderson et al., 2010; Prasciunas, 2011). For example, pertinent questions include whether and to what degree changes in numbers of points were influenced by: 1) changes in numbers of people or in settlement patterns; 2) reorganizations of technology; 3) biases in the collection of points; 4) errors in point identification or dating; 5) changes in the duration of point usage, both for an individual tool and for the point style; and 6) the effect of geological and biotic factors that may affect artifact deposition, preservation, and visibility. Nevertheless, in spite of these ongoing questions and potential limitations with PIDBA and other datasets, estimations of numbers of sites, artifacts, and/or radiocarbon dates continue to be widely used by archeologists as a proxy for human population size, an assumption used in this analysis (e.g., Rick, 1987; Gkiasta et al., 2003; Miller and Kenmotsu, 2004; Gamble et al., 2005; Thomas, 2008).

4. Analysis results (2): southeastern quarry assemblages

The documentation of Clovis and immediate post-Clovis use of quarry sites in the southeastern U.S. has not been an easy task, and reflects decades of collection and excavation by avocational and professional archaeologists. For the southeastern U.S., records were compiled of archaeological assemblages from eleven major stone quarry sites that were used extensively during the Clovis period and for most of prehistory thereafter. These represent major known quarry sites used by Clovis populations in the southeastern U.S that have been examined and reported in extended, albeit varying, levels of detail by archaeologists. This time series indicates minimal or no use of these quarries in the immediate post-Clovis 'full-fluted horizon' interval during the early YD (Figs. 6 and 7, Table 1). A major decline in population is thus suggested by these data. Alternatively, there may have been reorganizations in technology and/or settlement away from these sites, although this seems unlikely given that the decline in usage was so widespread, and the demand for the raw material itself was unlikely to have changed appreciably. Of the eleven sites examined, only one (Carson-Conn-Short) and possibly two others (Boyd-Ledford, Sinclair) exhibit evidence for presumably immediate post-Clovis utilization by makers of Redstone and Cumberland points, although even here the numbers are relatively low. Eight other sites have either no evidence for immediate post-Clovis usage (Wells Creek, Adams, Roeder, Ezell, and Big Pine Tree) or minor usage (Topper, Williamson, and Thunderbird). Based upon the quantity of cultural material catalogued at the best documented quarries (Carson-Conn-Short, Topper, and Adams), all three sites displayed a major decline in usage of greater than 98% (Fig. 7), with essentially negligible use during the early YD episode. Blades, blade core, and bifacial preforms are attributed to Clovis at some of these sites. While these placements are supported by site-specific analyses, as well as general observations about the likely temporal occurrence of these materials (e.g., Morrow, 1995, 1996; Collins, 1999, 2004; Tankersley, 2004), some of these artifacts, particularly some of the blades, may date somewhat later in the Paleoindian period (Sherwood et al., 2004:544; Fiedel and Morrow, in press). Given the low incidence of diagnostic immediate post-Clovis points at these same sites, however, the number of tools that may be temporally misattributed in Table 1 is likely quite low.

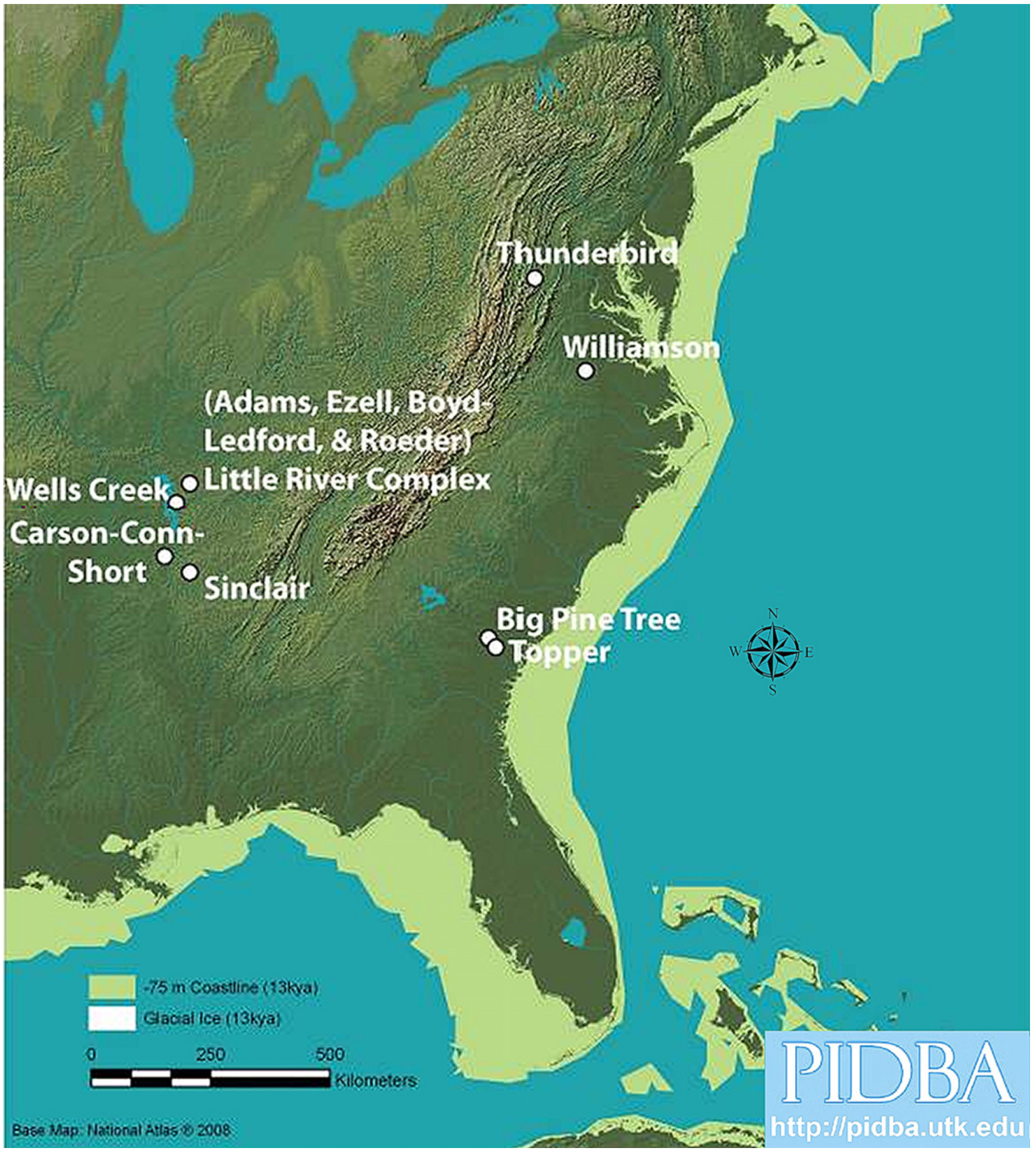

Fig. 6. Location of Clovis quarry sites examined in the Southeastern U.S.

Evidence from all the quarries supports the hypothesis that a major decline in human population or a change in settlement away from quarries occurred in those areas. Claims that reoccupation of such locations would not be expected given low population densities do not take into account that some of these quarry areas were primary stone sources for their respective regions, and/or were used throughout all subsequent periods of prehistory (Gardner, 1974; Goodyear and Charles, 1984; Tune, 2010). Resolving intensity of use of these sources throughout prehistory should be a focus for future research.

5. Analysis results (3): summed probability analyses

Further investigation of possible changes in North American human populations during the last deglacial interval from about 14,000 to 11,000 cal BP used summed probability analyses (SPA). This analysis relies on changes in the frequencies of radiocarbon dates from cultural sites (e.g., Rick, 1987; Housley et al., 1997; Gkiasta et al., 2003; Miller and Kenmotsu, 2004; Gamble et al., 2005; Thomas, 2008; Buchanan et al., 2008; Blockley and Pinhasi, 2011). The procedure involves calibrating cultural ^{14}C dates into

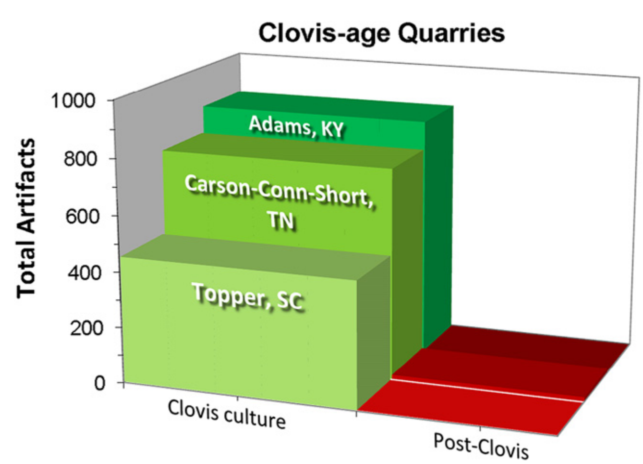

Fig. 7. Usage data from three Clovis-age quarries. This graph displays the total artifacts found (projectile points, preforms, cores, and blades) that can be attributed to Clovis and to the cultural traditions that followed immediately post-Clovis. All three sites display evidence of high Clovis usage, followed by major declines of more than 98% at the end of the Clovis cultural tradition ca. 12,900 cal BP.

Table 2
Databases employed in the Summed Probability Analyses.

Database name	# Dates	Authors	Region covered
Canadian Archaeological ^{14}C Database (CARD, 2009)	14423	Morlan and Betts (2005)	U.S., Canada, Russia
African Database: Egypt/Sudan	890	Hendrickx (2009)	Africa: Egypt, Sudan
Near East ^{14}C Database	4907	Böhner (2009)	Near East
INQUA Palaeolithic Database	5898	Vermeersch (2009)	Europe
CalPal Neolithic Database	9715	Böhner et al. (2009)	Mediterranean, Mideast, Europe
TOTAL ^{14}C DATES	35833		

calendar years and combining the probabilities using the 2D Dispersion Calibration algorithm supplied with CalPal-2007 (for details, see Methods). Major peaks and troughs in the trends are considered to be proxies for changing human population densities: greater numbers of ^{14}C dates are inferred to reflect larger populations, with fewer dates reflecting smaller populations. As with any analytical tool, SPA has limitations, including collection biases, factors of sample size and preservation, the varied accuracy and precision of the dates themselves, variation due to differing calibration programs, and the difficulties inherent in equating SPA values with human population (e.g., Rick, 1987; Surovell and Brantingham, 2007; Buchanan et al., 2008; Thomas, 2008; Steele, 2010). Despite these various biases and inaccuracies, the method is generally accepted as providing an approximation of long-term changes in population levels, especially when large samples are available. Regions examined and the sources of the databases employed in the analyses are given in Tables 2 and 3.

6. A test of SPA in North America

SPA was first used to test whether or not a long hypothesized decline in human and bison populations on the Great Plains during the Altithermal, or Atlantic period, an extended period of warming during the Mid-Holocene from ~9000–5000 cal BP, whose effects varied from region to region (Reeves, 1973; Frison, 1978:201; Wedel, 1986; Mayewski et al., 2004; Anderson et al., 2007), could be identified. Available dates from the Canadian Archaeological Radiocarbon Database (CARD, 2005) were divided into four regional groups in North America (Fig. 8). The data clearly demonstrate that from ~8800 cal BP, all regions examined throughout the continent show a major decline in ^{14}C cultural summed dates. In addition, a graph of available bison ^{14}C dates (bottom plot) displays a distinct, nearly synchronous decline in summed ^{14}C dates. Thus, the SPA results support the hypothesis that climate-related population declines or, alternatively reorganizations or relocations, occurred

Table 3
Sources of data by regions for all figures.

Fig.	Proxy	Time	Region	States, provinces, or countries	Data PTS	Data source
#3	Points	YD	Southeast, U.S.	AL, FL, GA, IL, KY, MS, MO, NC, SC, TN, VA, WV	7251	PIDBA
#4–5	Points	YD	Plains, U.S. + CAN	AR, AZ, CO, IA, ID, IL, IN, KS, MN, MO, MT, ND, NE, NM, OK, SD, TX, UT, WI, WY; **CAN:** SK	~14,000	PIDBA
#8	Dates	Altith.	East, U.S.	AL, CO, IA, KS, KY, MO, NC, ND, NE, NJ, NM, OK, SD, TN, TX, UT, VA, WI, WV	474	CARD, 2009
#8	Dates	Altith.	Neast, U.S. + CAN	CT, IN, MA, ME, MI, MN, ND, NH, NJ, NY, PA, SD, VT; **CAN:** LB, NB, NF, NS, ON, QC, NU	418	CARD, 2009
#8	Dates	Altith.	West, U.S.	AZ, CA, ID, MT, NV, OR, WA, WY	670	CARD, 2009
#8	Dates	Altith.	NWest, U.S. + CAN	AK; **CAN:** AB, BC, MB, NT, SK, YK	561	CARD, 2009
#8	Bison Dates	Altith.	U.S. + CAN	AK, CA, CO, FL, IA, ID, IN, KS, MN, MO, MT, ND, NE, NM, NV, OR, SD, TX, UT, WA, WY; **CAN:** AB, BC, MB, NT, NWT, SK, YK	620	CARD, 2009, Guthrie, 2006, Shapiro et al., 2004
#9	Dates	YD	U.S., SEast	AL, FL, GA, IL, KY, MO, NC, TN, VA, WV, SC, MS	127	CARD, 2009, Buchanan et al., 2008
#9	Dates	YD	U.S. + CAN: Plains	AR, AZ, CO, IA, ID, IL, IN, KS, MN, MO, MT, ND, NE, NM, OK, SD, TX, UT, WI, WY; **CAN:** SK	304	Buchanan et al., 2008
#9	Dates	YD	U.S., Alaska	AK	148	CARD, 2009
#9	Dates	YD	U.S. + CAN	AL, AZ, CA, CO, CT, FL, IA, ID, IL, KS, KY, MA, ME, MI, MN, MO, MT, ND, NE, NH, NJ, NM, NV, NY, OH, OK, OR, PA, SD, TN, TX, UT, VA, WA, WI, WY. **CAN:** AB, BC, NC, ON, SK	628	Buchanan et al., 2008
#10	Dates	YD	U.S. + CAN: E split	AL, CO, CT, DE, FL, IA, IL, IN, KS, KY, MA, ME, MI, MN, MO, NC, ND, NE, NH, NJ, NM, NY, OH, OK, PA, SD, N, TX, VA, VT, WI, WV; **CAN:** LB, MB, NS, ON, QC, SK	628	Buchanan et al., 2008
#10	Dates	YD	U.S. + CAN: W split	AZ, CA, ID, MT, NV, OR, UT, WA, WY, **CAN:** AB, BC	314	Buchanan et al., 2008
#10	Dates	YD	U.S. + CAN: N split	CT, ID, MA, ME, MI, MN, MT, ND, NH, NY, OR, SD, VT, WA, WI, WY; **CAN:** AB, BC, LB, MB, NS, ON, QC, SK	314	Buchanan et al., 2008
#10	Dates	YD	U.S. + CAN: S split	AL, AZ, CA, CO, DE, FL, IA, IL, IN, KS, KY, MO, NC, NE, NJ, NM, NV, OH, OK, PA, TN, TX, UT, VA, WV	314	Buchanan et al., 2008
#10	Dates	YD	U.S. + CAN: R split	Randomly selected	314 ea.	Buchanan et al., 2008
#11,12	Dates	YD	Europe	Albania, Austria, Belgium, Bosnia/Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, France, Georgia, Germany, Greece, Hungary, Italy, Netherlands, Poland, Portugal, Romania, Slovenia, Spain, Switzerland, Turkey, Ukraine, United Kingdom, Wales	361	Vermeersch, 2009; Böhner et al., 2009
#11,12	Dates	YD	Middle East	Iran, Iraq, Israel/Palestine, Jordan, Lebanon, Oman, Qatar, Saudi Arabia, Syria, Turkey, U.A.E., Yemen	443	Böhner, 2009; Böhner et al., 2009
#11,12	Dates	YD	Africa	Morocco, Egypt, Sudan	42	Böhner et al., 2009b; Hendrickx, 2009
#11,12	Dates	YD	Asia	Russia	195	CARD, 2009

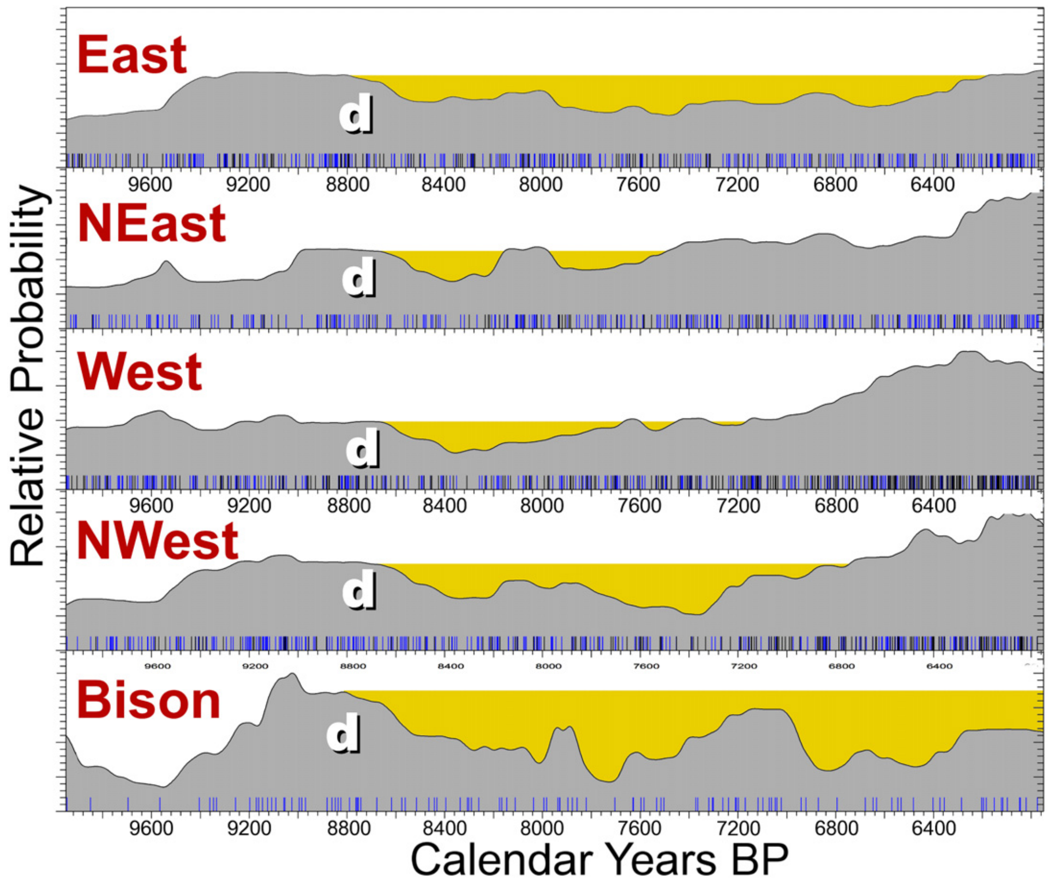

Fig. 8. Altithermal SPA plots of North American cultural ^{14}C dates from East to the Northwest, as well as a plot of continental bison dates. For this and following figures, the tick marks at the base of each plot represent individual calibrated median radiocarbon dates. Calendar years are on the *x*-axis and the *y*-axis displays curve amplitudes using a relative scale that applies only to each plot and cannot be used to compare demographic levels between regions. All of the declines began ca. 8800 cal BP, as marked at "d."

during the Altithermal. Note that for this and the following graphs, only the large-scale peaks or troughs are considered indicative of population changes, not the small-scale ones. For peaks and troughs, the age scale is only considered accurate to within ±200 calendar years, due to ^{14}C dating uncertainties and to imprecision in the summing algorithm. Because of these and other uncertainties, not all peaks during the early Holocene (10,000–6000 cal BP) co-occur, but most fall within the limits of dating uncertainty.

7. Younger Dryas SPA results for North America

The same ^{14}C dates published by Buchanan et al. (2008) and spanning from ~14,000 to 11,000 cal BP and including the YD interval, were used to analyze multiple regions of North America (Fig. 9). Contrary to Buchanan et al. (2008) and as supported by Steele (2010), there is an abrupt decline at the YD onset at or close to 12,900 cal BP, followed a few hundred years later by a distinct rebound that continued for several hundred years. The decline at the YD onset was more than 50%, similar in magnitude to the decline exhibited in the Clovis-Folsom point ratios, although less than the apparent change in quarry usage. While calibration and sampling factors unquestionably affect these trends, notably the rapid drop or 'cliff' in the calibration curve in the early YD (Broecker, 2009; Fiedel and Kuzmin, 2010; Steele, 2010; Fiedel, 2011), the observed declines are large and require careful consideration and explanation. Determining the calibration from ~12,900 to 12,600 cal BP is thus a critical area for research (e.g., Fiedel and Kuzmin, 2010; Steele, 2010).

7.1. Southeast

Fig. 9 (top panel) shows a decline at ~12,900 BP, followed by a rebound later in the YD that continued to the Holocene. The arrow marks a time after which there are ~80% fewer dates (uncertainty of ±20%) for the next ~300 years. Paleotemperature oscillations in the GISP2 Greenland ice core record exhibit roughly similar trends (bottom panel). A recent SPA analysis conducted using radiocarbon determinations from various subareas of Eastern North America, however, suggest that the decline at the YD onset was less pronounced in some areas, indicating human population response varied geographically (Miller et al., 2010; see also Holliday and Meltzer, 2010; Meltzer and Holliday, 2010).

7.2. Plains of central North America

SPA was conducted on cultural radiocarbon dates compiled from the same twenty-one U.S. states analyzed for Clovis-Folsom point frequencies. The "Plains" plot reveals a decline in amplitude at ~12,900 cal BP at the onset of the YD (Fig. 9). The arrow indicates the beginning of an 80% decline in the number of ^{14}C dates extending over the following ~200 years.

7.3. Alaska

Dates from several sources (Table 3) indicates evidence for a large increase in ^{14}C dates just before the YD (Fig. 9), followed by an abrupt decline immediately afterwards. That decline was lowest early in the YD although the number of dates then steadily rebounded during

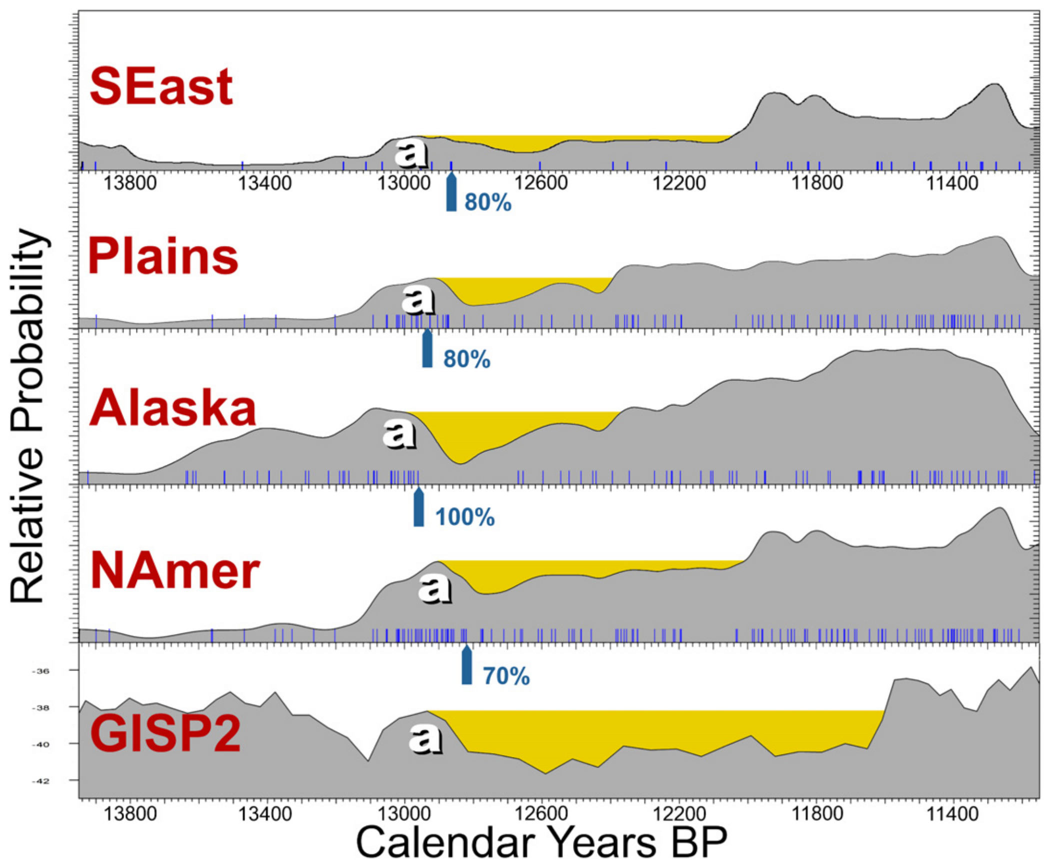

Fig. 9. SPA plots of cultural ^{14}C dates from the southeastern U.S., Plains, Alaska, and the North American continent. The declines in the number of cultural ^{14}C dates at or near the YD onset around "a" are marked by the arrows and range from 65% to 100% (with an uncertainty of ~20%). The Greenland ice core (GISP2) record of paleotemperature decline based on oxygen isotopic change (bottom panel), at the YD onset correlates closely with inferred population declines in several regions. GISP2 oxygen isotopic record smoothed at ~50 year intervals.

the late YD. The arrow identifies a time in Alaska at the onset of the YD after which there are no recorded cultural ^{14}C dates for more than 200 years, suggesting a possible human bottleneck.

7.4. North America

The plot for North America (Fig. 9) includes all dates used by Buchanan et al. (2008) and, save for a narrower temporal range, is essentially identical to their published graph. For 682 North American cultural ^{14}C dates, there is a large increase that began just before the onset of the YD followed by a rapid decline at the beginning of the YD that reached its lowest level early in the YD, followed by a gradual rebound for ~900 years. The arrow marks a 200-year-long, 80% decline in the number of cultural ^{14}C dates, implying a major decrease in population. The GISP2 paleotemperature record from the Greenland ice sheet (bottom panel) generally matches the increases and declines in summed probabilities in the centuries immediate at and after ~13,100 cal BP, but it is clear that human populations rebounded during the later YD even though temperatures remained cool. These results are consistent with previous broad observations in California for a 600–800 year gap in the archeological record beginning at the YD onset (ca. 12,900 cal BP) considered to reflect a depression in human populations (Johnson et al., 2002; Jones, 2007; Kennett et al., 2008).

8. SPA results for North America

Buchanan et al. (2008) recognized a decline in ^{14}C summed probabilities at ~12,800 cal BP, approximately the time of the YD onset or slightly later, but interpreted that decline as relatively minor, essentially no more significant from other fluctuations observed from ~13,000 to 9500 cal BP. To evaluate whether or not the decline observed in many areas after ~12,900 cal BP represented noise, a test was conducted in which the radiocarbon database was divided into several different regions and random subsets and those probabilities were summed separately. The analytical test showed a persistence of the apparent decrease at the YD onset in the different regions and subsets (Fig. 10). This result is inconsistent with an insignificant decline or random noise, but rather offers support for the hypothesis that human population decline occurred in the centuries immediately after ~12,900 cal BP. Note that in all of the plots in Fig. 10, population peaks at "a" and "c" co-vary with the apparent paleotemperature oscillations in the GISP2 ice record. However the peak ("b") in the SPA plots centered at ~12,000 cal BP in the late YD, reflecting an apparent rebound in human populations, shows minimal correlation with the GISP2 climatic record. Thus, although climate appears to have played an important role in changing human population densities at the onset of the YD, it had less of an impact during the later YD, when climate continued to be cool. Human populations in North America, the SPA analyses indicate, thus appear to have adapted to the YD within a few centuries in many areas, although response/rebound times also appear to have varied somewhat.

9. SPA results on other continents

Using the radiocarbon databases in Tables 2 and 3, SPA were conducted with cultural ^{14}C dates for other parts of the Northern Hemisphere (Fig. 11) to determine whether or not a decline

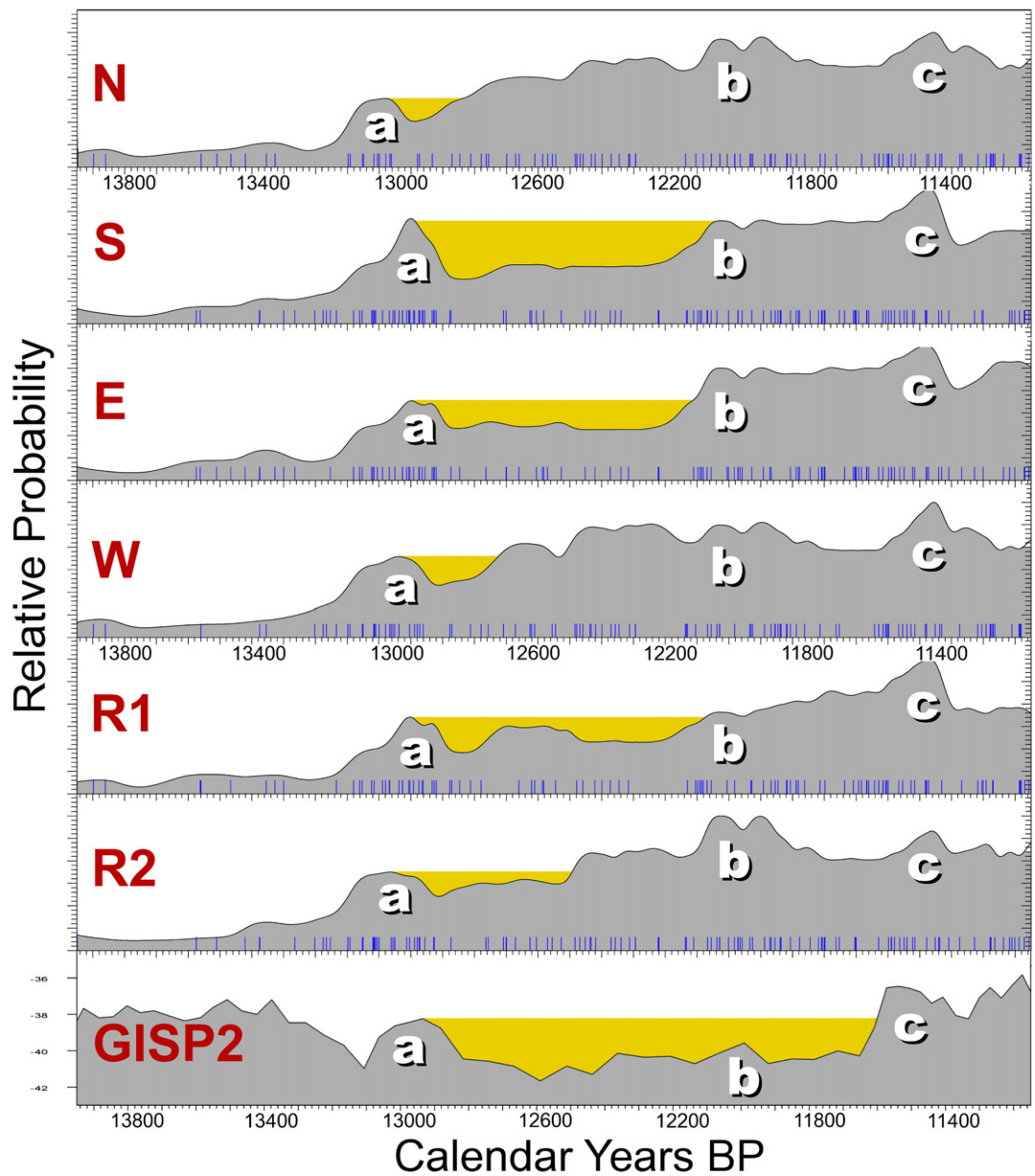

Fig. 10. SPA plots of cultural ^{14}C dates from geographical and sample subsets from North America. In all tests, the dates were calibrated with IntCal04 and their probabilities summed using CalPal-2007. Three sets of data splits were tested on North American cultural ^{14}C dates: north-south ("N", "S"); east-west ("E", "W"); and random halves ("R1", "R2"). Population peaks at "a" and "c" correspond closely with the temperature peaks in a Greenland (GISP2) ice core record, but not the clear rebound peak "b" at ~12,000 Cal BP that occurred during continued YD cooling. GISP2 oxygen isotopic record smoothed at ~50 year intervals.

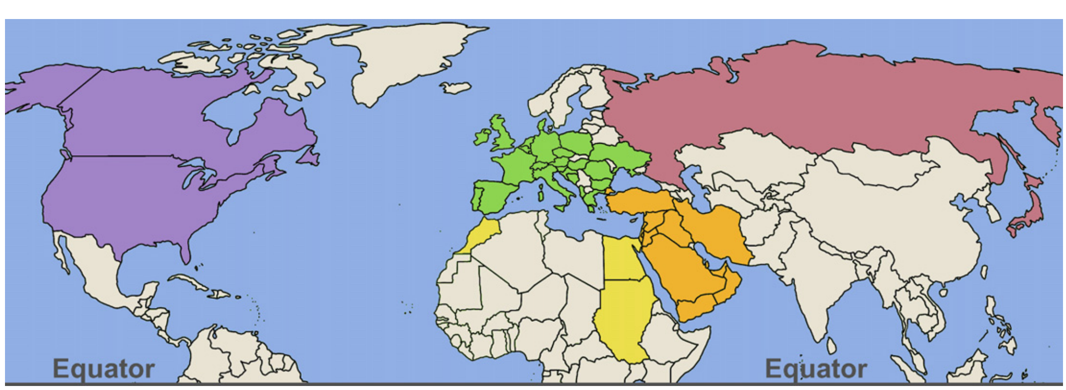

Fig. 11. Regions in Northern Hemisphere analyzed with summed probability: North America (purple); Europe (green); Africa (yellow); Middle East (orange); and Russia (red). See Table 3 for a list of countries studied. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

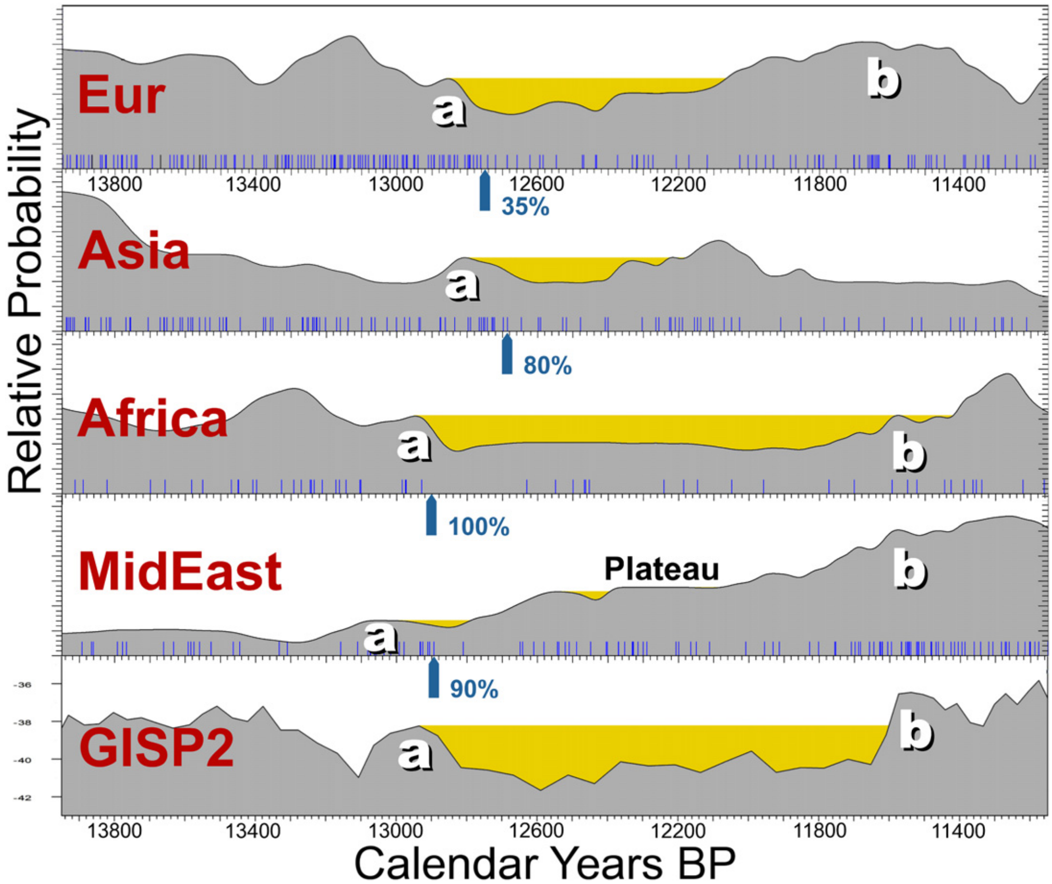

Fig. 12. Summed probabilities of cultural ^{14}C dates by continental region used to infer human population trends at "a" at and following the YD onset. The arrows mark the beginning a 200-year interval during which numbers of dates drop by 35–100% compared to the previous 200 years. The onset of the Holocene is at "b" corresponding to 10,000 ^{14}C BP. GISP2 oxygen isotopic record smoothed at ~50 year intervals.

occurred at the onset of the YD. These results (Fig. 12) are similar to those in North America in some but not all areas (i.e., the Mideast). Apparent population declines or plateaus associated with the YD onset appear in all continental areas north of the equator.

Europe displays a drop in ^{14}C summed probabilities of about 35% (arrow), with the largest drop occurring at the onset of the YD ~12,900 cal BP. The apparent decline began at "a" and lasted for about 800 years before recovering. In Asia, the steepest and deepest part of an amplitude decline (arrow) also occurred early in the YD after "a". The decline amounted to 80% fewer dates than in the preceding 200 years. A brief recovery occurred about 600 years later during the YD, followed by another decline. For Africa, the plot and number of dates plummeted early in the YD, with inferred population levels not recovering until ~1300 years later during the initial Holocene. In contrast, the SPA plot of the cultural ^{14}C record for the YD in the Middle East is unlike those for the other areas examined, in North America, Europe, portions of Asia, and Africa. No evidence for a significant decline is evident at the YD onset, instead growth followed by a lengthy plateau is indicated, suggesting that the Mideast may have served as a refugium for humans (but see Bar-Yosef and Belfer-Cohen, 2002; Blockley and Pinhasi, 2011). In all panels of Fig. 12, the population peaks shown at "a" and "b" correspond reasonably well with climatic warming episodes shown in the GISP2 record at bottom, as is the case for North America.

10. Conclusions

All three datasets, projectile points, quarries, and SPA data, indicate that a major human population decrease (bottleneck), or alternatively population reorganizations (i.e., dramatic changes in settlement patterning), occurred over broad areas of North America at the onset of the YD cooling episode ~12,900 cal BP. The SPA results provide evidence that similar declines or changes occurred across much of remainder of the Northern Hemisphere with the exception it, seems, of the Middle East. In addition, the SPA results suggest that a population decline also occurred during the Altithermal in the Mid-Holocene, beginning ca. ~9000 years ago and lasting for 1000 years or more.

Caution, of course, is warranted in interpreting all of these results because sampling biases, oscillations in the radiocarbon calibration curves, different methods of dating and different calibrations, as well as variation in human response to climate change complicate such analyses. Nevertheless, a wide range of evidence indicates that conditions during the initial few centuries of the YD caused a significant drop in human populations or dramatic reorganizations of settlement in North America and possibly also broadly throughout the Northern Hemisphere. In the latter half of the YD, a rebound in population or settlement is indicated by increased numbers of projectile points, increased quarry usage, and trends indicated by SPA datasets in most areas. In contrast to the onset of the YD, this rebound took place during a time of continued climatic cooling in the later part of the YD, suggesting other factors were at play in addition to climate. This initial test of the efficacy of SPA, to monitor a long hypothesized apparent decline or reorganization/relocation in human and bison populations during the Mid-Holocene/Altithermal yielded supporting patterning, which suggests that this form of analysis should also yield useful results when examining population trends during earlier periods, as herein for the YD. To the best of the authors' knowledge, this is the first time that a continental population pattern has been proposed for the Altithermal using SPA and is also the first time that a hemispheric pattern has been suggested for the YD. These changes in climate and human population size are at least in part related. The change at the onset of the YD appears to have occurred fairly abruptly and, at least in some areas, may have resulted in human population declines of up to 30%–50%, with rebound occurring at varying rates in the centuries that followed.

Acknowledgments

The authors wish to thank Stuart J. Fiedel, Ted Goebel, Erik Johanson, Shane Miller, Kenneth E. Sassaman, Thomas W. Stafford, Jr., Stephen J. Yerka, and two anonymous reviewers for their advice and comments during the the preparation of this paper. The research reported herein was facilitated by interactions with numerous colleagues in recent years, whose openness and assistance is deeply appreciated. Those interested in furthering the work with PIDBA are encouraged to submit primary data for posting.

Appendix. Methods

Method #1. Projectile point counts as compiled in PIDBA (Anderson et al., 2010) were used. After creating subsets of the approximately 14,000 points that can be attributed to Clovis, Folsom, and contemporaneous cultures, points were totaled by type and region and the results plotted (Figs. 3–5).

Method #2. Published studies of eleven lithic quarries that were being used by Clovis peoples around 13,000 years ago (Fig. 6, Table 1) were used to compile and graph the number of cultural artifacts (e.g., projectile points, preforms, cores, and blades) across the interval that includes usage by Clovis and immediately post-Clovis cultures.

Method #3. The 628 ^{14}C dates that were used for the interval spanning the YD in North America were taken from Buchanan (2008). For the Altithermal and Old World SPA dates, from about 36,000 ^{14}C dates compiled in publicly available databases for Europe, Asia, and the Middle East, all dates that fell within the range of 10,000 to 5000 ^{14}C years for the Altithermal and 13,000 to 9000 ^{14}C years for the YD (see Tables 2 and 3) were selected, including only those ^{14}C dates that were associated with cultural material. This study did not determine the accuracy of those dates, assuming, as Buchanan et al. (2008) did, that potential errors would be offset by a large number of dates. Lastly, the dates were calibrated using the IntCal04 reference curve (Reimer et al., 2004) available within CalPal-2007, and summed probability plots were generated using the 2D Dispersion Calibration algorithm supplied with CalPal-2007. Using the IntCal09 reference curve (Reimer et al., 2009) yields somewhat different results (e.g., Steele, 2010).

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