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Possible impacts of early-11th-, middle-12th-, and late-13th-century droughts on western Native Americans and the Mississippian Cahokians

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Abstract

One or more of three intense and persistent droughts impacted some Native American cultures in the early-11th, middle-12th and late-13th centuries, including the Anasazi, Fremont, Lovelock, and Mississippian (Cahokian) prehistorical cultures. Tree-ring-based reconstructions of precipitation and temperature indicate that warm drought periods occurred between AD 990 and 1060, AD 1135 and 1170, and AD 1276 and 1297. These droughts occurred during minima in the Pacific Decadal Oscillation and may have been associated with positive values of the Atlantic Multidecadal Oscillation. Each of the Native American cultures was supported, to a greater or lesser degree, by precipitation-dependent resources. Both the Four Corners region and Cahokia were sites of intense growth between about AD 1050 and 1130, and by AD 1150, cultures in both regions were undergoing stress. By AD 1300 the Anasazi and Fremont cultures had collapsed and their residual populations had either left their homelands or withered. In the case of Fremont populations, the AD 990–1060 drought may have had the greatest impact. This drought also may have affected the Anasazi, for it was at the end of this drought that some people from Chaco migrated to the San Juan River valley and founded the Salmon Ruin great house. Detailed data do not exist on the number of Lovelock habitation sites or populations over time; however, Lovelock populations appear to have retreated from the western Great Basin to California by AD 1300 or shortly thereafter.
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1. Introduction

The response of a human population to climate change is largely a function of the sensitivity of that population's resource base to that change. For example, if an agrarian culture overexploits the surrounding environment and greatly increases its population, or if hunter-gatherers depress their natural resource base resulting in declining prey-capture rates, an abrupt change in climate may result in population declines and lead to cultural collapse.

This position is consistent with Binford's (1972) suggestion that a culture will continue to function as long as changes in the external environment are sufficiently gradual so that the culture can adapt to those changes. If, on the other hand, the homeostatic range of that culture is exceeded by an external shock (such as drought), that culture may be incapable of dealing with the added stress.

Recent publications (e.g. Jones et al., 1999; Gill, 2000; Kennett and Kennett, 2000, 2006; Drysdale et al., 2006; Turney et al., 2006) indicate a renewed interest in the possibility of climatic forcing of cultural change, and scholars such as Dean et al. (2000) and Axtell et al. (2002) have applied agent-based models in which climate forcing

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of maize yields is used to simulate population movement within the Four Corners region. We think this emphasis has merit and, in the following, we discuss the possible impacts of early-11th-, middle-12th-, and late-13th-century droughts on some Native American cultures that occupied parts of the western United States (US) and the Cahokia area in present-day southwestern Illinois. In particular, we examine the responses of Anasazi, Fremont, Lovelock, and Mississippian cultures (Fig. 1) to droughts that occurred between AD 990 and 1060, AD 1135 and 1170, and AD 1276 and 1297 (Fig. 1b-d).

In the following, we present evidence indicating correlations in time between persistent multidecadal droughts and demographic shifts among some prehistoric Native American populations. We also offer broad-brush explanations with respect to the effect of drought on the subsistence base(s) of agriculturalists and hunter-gatherers. More specifically, we show how drought may have impacted dry-land farming in the Four Corners region and how it may have impacted water bodies in the western Great Basin. Although the effects of drought include other phenomena such as warfare, reduced reproduction rate,

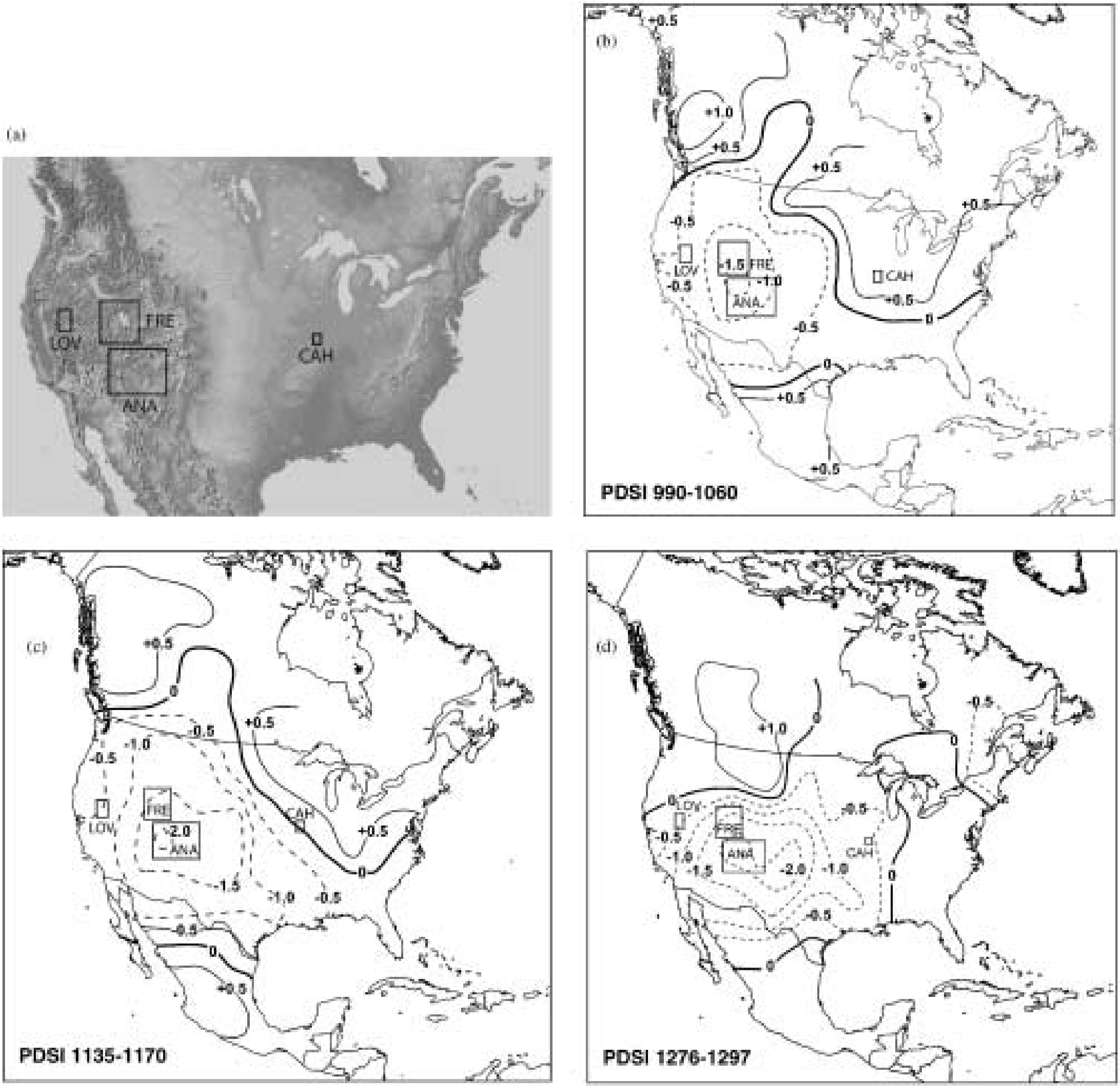

Fig. 1. Approximate locations of the Anasazi (ANA), Fremont (FRE), Lovelock (LOV), and Mississippian Cahokian (CAH) cultures are shown as black-bounded rectangles in (a). Palmer Drought Severity Index (PDSI) reconstructions for the contiguous US for the periods (b) AD 990–1060., (c) AD 1135–1170, and (d) AD 1276–1297 (Cook et al., 2004). Negative PDSI values indicate drought.

and changes in diet breadth, detailing evidence for such phenomena are beyond the scope of this paper. It is our hope that members of the archaeological community will attempt to test our hypothesis of drought forcing of Native American migrations by providing archaeological evidence for or against such phenomena.

Estimation of changes in prehistoric populations usually involves three steps: (1) enumeration of habitation sites, (2) assignment of numbers of individuals relative to a particular structure (e.g., a kiva or a room) or to a particular floor area (see, e.g. Stubbs, 1950; Drager, 1976; Windes, 1984), and (3) dating of the structure. Each of these steps is associated with appreciable error.

In the case of habitation-site enumeration, not all sites have been discovered, and enumeration is usually neither a random nor a systematic process. For example, in the past, archaeologists emphasized the excavation of large standing structures such as great houses as opposed to small residential structures. In the last 50 years (yr), many small Anasazi sites have been discovered during spatially restricted surveys involving constructions of roads, reservoirs, etc. However, “contributing surveys” have been done which have a large areal extent, and in which all dwellings within the survey area have been located (e.g., Marshall et al., 1979).

Site numbers can be misleading when dealing with fulltime foragers. Relatively sedentary foragers, occupying productive habitats, may produce fewer sites than highly mobile foragers, moving frequently among relatively unproductive habitats. In such a situation, habitation site number may actually increase during a drought-induced decrease in the subsistence base. Given the difficulty of associating numbers of people with building features, and given the dearth of building features for some of the cultures (e.g., the Lovelock) discussed in this paper, estimates of Native American populations will not be emphasized.

Tree-ring dates of human dwellings indicate the time of cutting and the approximate time of construction; however, they do not necessarily allow an accurate estimation of the length of time of occupation. Instead, radiocarbon dates or ceramic chronologies are often used to determine site residence times. Ceramic dating at its best is probably no more accurate than ±50–100 yr, and conversion of radiocarbon to calibrated calendar ages is done in a variety of ways such that the results are not always consistent from study to study.

2. Native American population dynamics

Given the above cautionary comments, the population dynamics of five Native American groups are discussed in the following subsections.

2.1. Anasazi population dynamics

The Anasazi are thought to be the ancestors of present-day Pueblo people who occupy villages in New Mexico and Arizona. The emergence of Anasazi culture is generally associated with the introduction of pottery (at about AD 200–300) to an Archaic lifestyle that combined maize agriculture with hunting and gathering (Cordell, 1994).

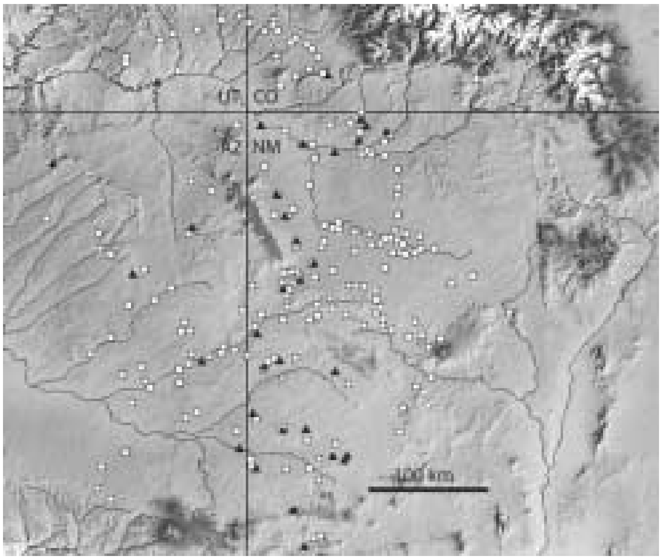

Fig. 2. Anasazi great houses in the Four Corners region. The white squares indicate great-house communities that were abandoned by 1130/1150 AD; the black triangles indicate great-house communities that persisted until 1300 AD Information portrayed on the map was taken from Fowler and Stein (1992); additional unpublished data on great-house locations in the southwestern and western San Juan Basin were compiled by Rich Friedman and John Stein based on fieldwork conducted between 1984 and 2004.

Over time, the Anasazi became more sedentary as witnessed by evolution in the form and size of their dwellings and villages. Early Anasazi were fairly mobile and tended to move every generation or so, and in a sense, early pueblo people were nomadic agriculturalists. Between AD 700 and 900, Anasazi architecture took the form of surface pole-and-mud storage rooms constructed adjacent to circular or square-shaped pithouses. By AD 850, stone multistory structures (great houses) were under construction in the San Juan Basin (e.g., Pueblo Bonito; Windes, 2003). Construction of greathouses accelerated between AD 1050 and 1130, and by the end of this period over 207 great houses existed in the Four Corners region (Fig. 2) (Kantner and Mahoney, 2000; Kantner, 2003). Thus, the changing architecture of the Anasazi can be interpreted to indicate a culture that evolved to a relatively sedentary agricultural lifestyle in which maize was a dietary staple. Stuart (2000, p. 7) has estimated that between 10,000 and 20,000 farmsteads populated the Four Corners region by the late-11th century. This is not to say that the Anasazi did not forage in the 11th and 12th centuries but that agriculture dominated their subsistence base.

During the middle-12th century, most of the great houses in the central San Juan Basin were vacated and, during the late-13th-century, most of the remaining great houses and many of the smaller villages in the Four Corners region were abandoned (Fig. 2). Tree-ring-dated

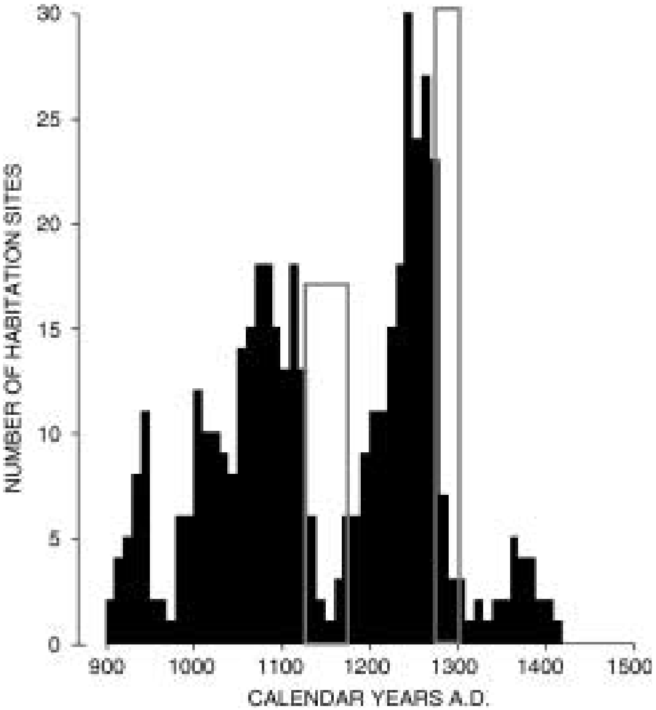

Fig. 3. Number of tree-ring-dated habitation sites from the Four Corners area as of 1982 (Berry, 1982). Habitation site number should not be considered equivalent to a specific population value as it is only a rough nonlinear measure of population. Vertical gray-bounded rectangles delineate middle-12th- and late-13th-century droughts.

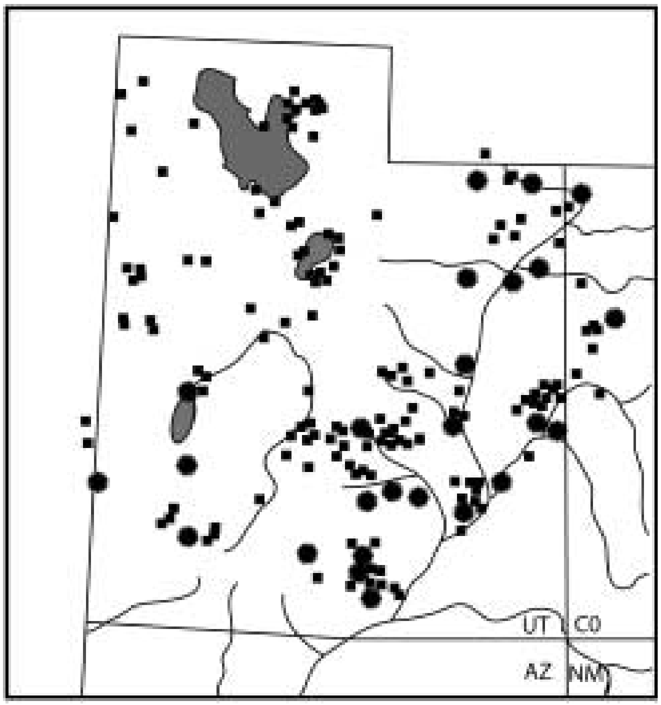

Fig. 4. Location of Fremont sites in Utah and surrounding areas (Berry and Berry, 2003). Solid squares indicate single sites and star bursts indicate village clusters. Thin black lines indicate drainages.

habitation sites also indicate rapid population declines beginning at AD 1130 and 1280 (Fig. 3) (Berry, 1982). Anasazi groups that occupied lands in southwestern Utah; e.g., the Virgin River Anasazi also abandoned their settlements during the middle-12th-century (Larson and Michaelsen, 1990; Lyneis, 1996).

2.2. Fremont population dynamics

The Fremont have been loosely defined in terms of their horticulture, sedentism, and ceramic traditions. It has been suggested that the Fremont consisted of groups that practiced variable settlement and subsistence patterns over time and space (Madsen and Sims, 1998; Spangler, 2000) and that some Fremont were full-time farmers, some were full-time foragers, and some practiced a mixture of farming and foraging. However, it is also possible that the archeological remains within the Fremont area represent a multi-ethnic cultural landscape consisting of indigenous hunter-gatherers and immigrant agriculturalists. The level to which the full-time foragers participated in Fremont culture beyond trade relationships remains a topic of some interest but one which will not be dealt with in this paper.

Talbot and Wilde (1989) were among the first to study Fremont population variability based on an examination of about 427 dates, including 38 tree-ring dates. Their assumption of a 30-yr range for all ^{14}C dates and their conversion (calibration) of ^{14}C dates to calendar yrs has been criticized by Massimino and Metcalfe (1999) who used a more rigorous sample selection procedure and a method of calibration that included consideration of one-sigma and two-sigma calibrated age ranges calculated using a 1993 version of CALIB (Stuiver and Reimer, 1993). They found step-function declines in eastern Great Basin sites (206 dates) beginning at AD 1150 and 1300 and declines in northern Colorado Plateau sites (137 dates) beginning at AD 1000, 1150, and 1300.

Berry and Berry (2003) have accumulated over 2000 ^{14}C dates on Fremont sites in the southern Basin and Range and Colorado Plateau (Fig. 4). Each ^{14}C date used by these authors was weighted inversely to its squared sigma relative to the largest sigma in the data set, resulting in an inverse dispersion weight. The ^{14}C date was then calibrated by inputting the one-sigma ^{14}C confidence interval into CALIB Version 4.3 (Stuiver et al., 1998). The probabilities of the resulting date ranges were then multiplied by the inverse dispersion weight and the resulting cumulative habitation weights for each 10-yr bin were summed. The resulting data indicate habitation declines, beginning between AD 1000 and 1050 and at AD 1280 (Fig. 5).

Population expansions and contractions were not synchronous across the entire region occupied by the Fremont; e.g., in northwestern Utah, population declines begin at AD 1050, 1160, and 1290 (Berry and Berry 2003, Fig. 11a). Spangler (2000) performed a regional-scale study of Fremont population change in which he attempted to discriminate between sedentary and hunter-gatherer sites.

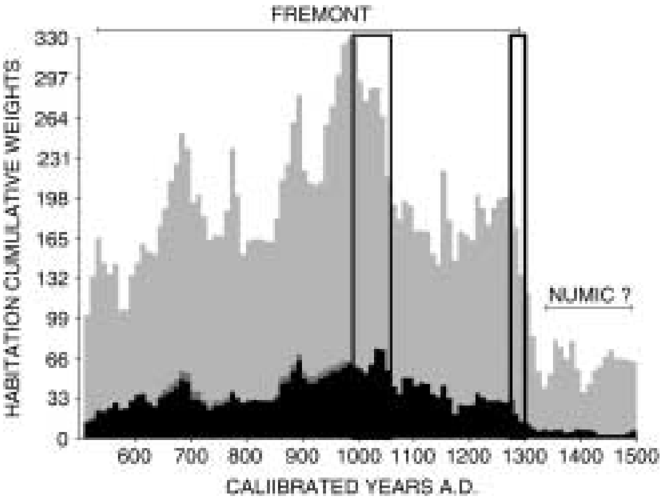

Fig. 5. Habitation cumulative weights for the Fremont "area". High-credibility short-lived organics for each 10-yr bin are shown in black. Intermediately credible samples (e.g., the outer 10 rings of charred beams) are shown in dark gray, and low credibility wood charcoal samples are shown in light gray. Each ^{14}C date was weighted inversely to its squared sigma relative to the largest sigma in the data set resulting in an inverse dispersion weight. The ^{14}C date was then calibrated using CALIB Version 4.3 (Stuiver et al., 1998) using the one-sigma ^{14}C confidence interval. The probabilities of the resulting date ranges were then multiplied by the inverse dispersion weight and the resulting weights for each 10-yr bin were summed (Berry and Berry, 2003). Vertical rectangles delineate early-11th- and late-13th-century droughts.

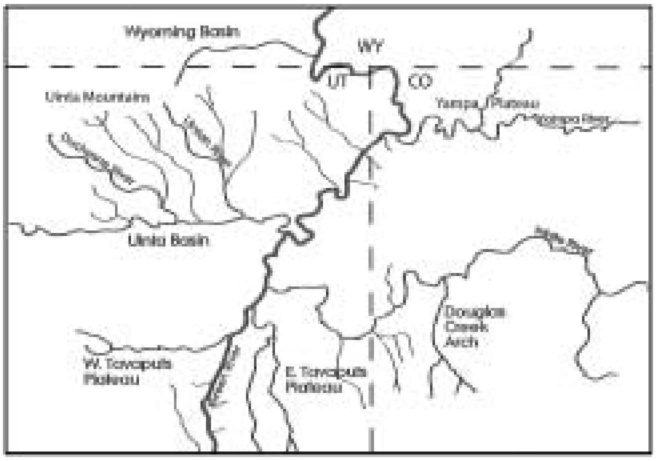

Fig. 6. The greater Uinta Basin area. The northern part of the basin is defined as the area above the Duchesne and White rivers and is termed the "Uinta Basin". The southern part of the area below the two rivers is termed the "Tavaputs Plateau" (Spangler, 2000).

In general, the type of habitation was defined on the basis of its location with regard to resource area(s). Those sites that contained long-term permanent-habitation structures located near potential agricultural field sites (e.g., floodplains) and that also contained such items as ceramics and groundstones were defined as "sedentary" sites. Semi-permanent or temporary sites (e.g. rockshelters) generally lacking such material culture and that had a wild-plant focus were defined as "hunter-gatherer" sites.

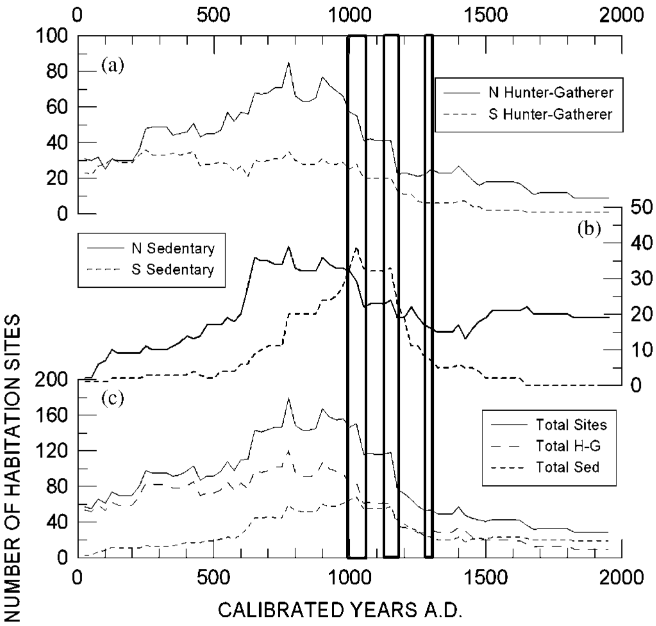

Fig. 7. (a) Variation in Fremont northern (N) and southern (S) hunter-gatherer sites between AD 0 and 2000. (b) Variation in Fremont northern (N) and southern (S) sedentary sites between AD 0 and 2000. (c) Variation in Fremont hunter-gatherer (H-G), sedentary (Sed), and total sedentary plus hunter-gatherer sites between AD 0 and 2000 (Spangler, 2000; unpublished data of J. Spangler). Vertical rectangles delineate early-11th-, middle-12th- and late-13th-century droughts.

Spangler (2000) showed that a maximum in sedentary horticultural sites in the northern part of the greater Uinta Basin occurred between AD 640 and 1000, whereas, in the southern part of the basin, a maximum in sedentary sites occurred between AD 1000 and 1150 (Figs. 6, 7a, b). A decline in hunter-gatherer sites in the northern part at about AD 990 and again at about AD 1150 was coincident with, respectively, declines in the number of northern and southern sedentary sites. By around AD 1300, the number of sedentary and hunter-gatherer habitation sites had plateaued at low values (Fig. 7a, c). Thus, data from the greater Uinta Basin area indicate a shifting in horticultural intensity from the northern to the southern part of the basin at about AD 1000 with a later decline in overall population commencing during the middle-12th-century.

2.3. Lovelock population dynamics

The prehistoric Lovelock Culture was initially defined on the basis of cultural deposits excavated by Loud and Harrington (1929) at Lovelock Cave, Nevada (Fig. 8). The Lovelock lifestyle is characterized as an intensive lake–sink–marsh adaptation, intensive use of caves and rock-shelters surrounding lakes, sinks, and marshes, and a suite of distinctive artifact types. Lovelock material culture includes the following diagnostic artifact types: large, shaped mortars with conical grinding areas and biconical pestles, Lovelock Wickerware burden baskets, coiled winnowing and parching trays, coiled water bottles, finely

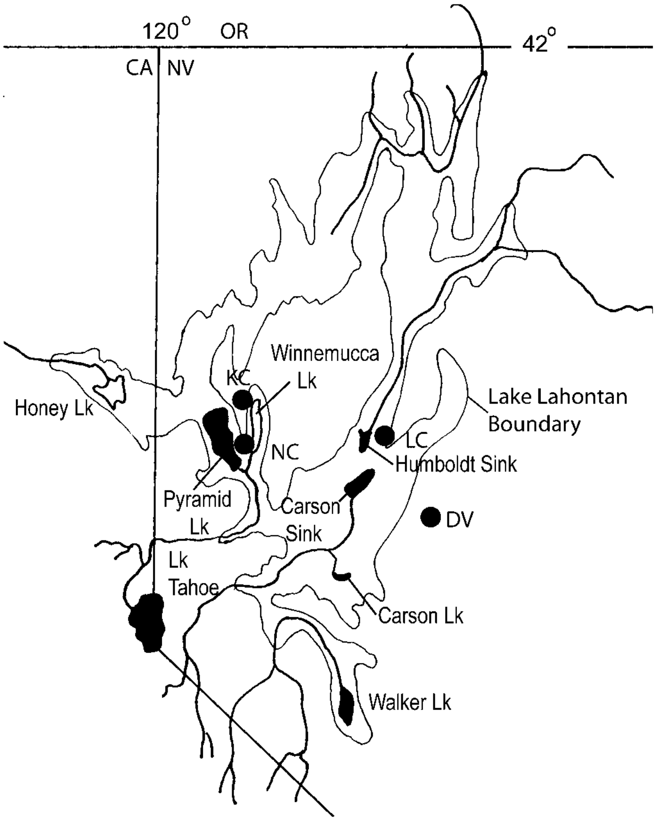

Fig. 8. Map showing locations of Lovelock archeological sites discussed in text, as well as lakes and sinks in the Lahontan Basin. Archeological sites include Kramer Cave (KC), Nicolarsen Cave (NC), Lovelock Cave (LC), and Dixie Valley (DV). Outline of Lake Lahontan shown by thin solid line.

woven, feathered coiled basketry, L-shaped scapula awls, fishhooks, tule duck decoys, and zoomorphic figurines (Grosscup, 1960). In the following, we use distinctive three-rod-foundation coiled basketry and Lovelock Wickerware basketry as hallmarks of the Lovelock Culture, and to define their approximate tenure in the western Great Basin.

More than 1000 fragments of Lovelock Wickerware basketry were recovered from Lovelock Cave, Nevada. Originally, the wickerware probably was in the form of conical, burden baskets. Lovelock Wickerware is known only from the Humboldt Sink, Pyramid and Winnemucca lake basins, the Carson Desert, and, possibly, Dixie Valley in western Nevada (Fig. 8).

There are relatively few direct dates on Lovelock Wickerware, but existing dates range from 3270±180 to 580±100 ^{14}C yr B.P. (1573±200 BC to AD 1336 ±38)[1] (Tuohy and Hattori, 1996). The 580±100 ^{14}C date is a single, composite date derived from three samples; thus, one of the three Wickerware samples is most likely younger than the composite date. Five Lovelock wickerware samples that we had dated for this paper had calibrated ages that fell within the existing age range (Table 1).

Coiled basketry initially appears in western Nevada around 3830±30 ^{14}C yr B.P. (2233±28 B.C.) and persists until at least 759±33 ^{14}C yr B.P. (AA64981; AD 1265±14) (Hattori, 1982) (Fig. 8). The latter date was recently obtained on a coiled, willow water bottle (180-L-12/S-58) from Lovelock Cave. Therefore, the dates for Lovelock Wickerware, and three-rod coiled basketry suggest that the Lovelock people occupied parts of the western Great Basin between about 2200 B.C. and about AD 1300.

2.4. Cahokian population dynamics

We have relied heavily on the work of Timothy Pauketat (Pauketat, 2004) in the following sketch of Cahokian prehistory. Cahokia is one of three large Mississippian archaeological sites that made up a part of a large political-administrative complex in the middle Mississippi River Valley (Fig. 1a). By AD 900, maize agriculture was firmly established along river valleys in the central lowlands surrounding Cahokia, and between AD 900 and 1050, agricultural intensification occurred. During this period, population increased in the American Bottom of the Mississippi River Valley as the result of in situ population growth as well as movement of people from adjacent interior uplands and stream valleys.

Between AD 1050 and 1100, Cahokia's population increased from between 1400 and 2800 people to between 10,200 and 15,300 people (Pauketat, 2003) and it has been estimated that the regional population swelled to between 30,000 and 50,000 people (Pauketat, personal communication, 2006). Cahokia was the site of over 120 pyramidal mounds, the largest of which (Monks Mound) was 30-m high with a base that covered 7 ha. Thousands of wooden pole-and-thatched buildings flanked the mounds.

The Cahokians' diet was not restricted to maize and squash but also included deer, fish, shellfish, waterfowl, nuts, and seeds, all of which were abundant in the Mississippi Valley and adjacent highland areas (Smith, 1975; Rees, 1997). Between AD 1050 and 1200, new floodplain farmlands and upland villages were established, including the Richland complex in the uplands east of Cahokia which contained between 3000 and 7500 resident farmers. This upland farming complex is considered to have been a major supplier of foodstuffs (e.g. maize) to downtown Cahokia (Alt, 2001; Pauketat, 2004).

The downtown area of Cahokia was the site of large-scale public events that featured feasting. These occasions may have involved the redistribution of surplus food and public works projects such as incremental mound construction.

Cahokia exerted influence outside its immediate area; e.g., Ramey-incised pots and Long-Nosed-God ear ornaments produced in Cahokia have been found as far north as Wisconsin and as far south as Louisiana (Fig. 6.1 in Pauketat, 2004). Despite being the largest political and

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[1] All radiocarbon dates on Lovelock materials have been calibrated using CALIB 5.01 (Stuiver et al., 1998). The ± value indicates the most probable age range and the number preceding the ± value indicates the midpoint of the range which we assume to be the most probable age of the object.

Table 1
New Lovelock wickerware dates for the western Great Basin

Sample	Location	Lab no.	^{14}C date (yr B.P.)	^{14}C error ($1-\sigma$ yr B.P.)	^{13}C (‰)	Cal age ($1-\sigma$ AD)	Probability (%)
26Ch5/19920	Lovelock Cave	ETH 31920	1620	40	−25.4	395–442	0.49
26Ch5/19921	Lovelock Cave	ETH 31921	1605	40	−23.2	482–533	0.53
26Wa6914-92	Charlie Brown Cave	CAMS123691	1505	30	−25.8	542–598	1.00
26Wa6914-12t	Charlie Brown Cave	CAMS123693	1330	45	−24.4	652–708	0.79
DV#2 Ransom Cave	Dixie Valley?	CAMS123694	1295	30	−25.7	670–713	0.65

religious center of the Mississippian civilization, Cahokia declined as rapidly as it formed. It may have formed through aggregation of distinct Native American groups and, in turn, it may have unraveled as those groups split off. Indications of political unrest in Cahokia appeared in the AD 1100 s when walls were first constructed. In AD 1150, a 3-km-long 20,000-log palisade was placed around downtown Cahokia (Iseminger et al., 1990). This wall was built and rebuilt at least four times during the following 50 yr (Pauketat, 2004). At the same time, the entire Richland farming complex was abandoned. These events indicate that the farming population was declining, leaving Cahokia without a strong economic base, and that the Cahokian population felt threatened. Cahokia's final abandonment is evidenced by late-Mississippian cemeteries, the last of which dates from AD 1275 to 1300 (Emerson and Hargrave, 2000).

3. Climate reconstructions and droughts of the early-11th, middle-12th, and late-13th centuries

In the preceding sections, population declines among the various Native American cultures were documented to have occurred either in the early-11th, middle-12th, or late-13th centuries. In the following we will demonstrate that areally extensive droughts impacted the regions occupied by these prehistoric Native Americans during one or more of these three time periods.

Persistent droughts frequently occurred in the western United States during the late Holocene. For example, a 2630-yr δ^{18}O record of volume change for Pyramid Lake (Benson et al., 2002) indicates that multiyear drought occurred, on average, every 150 yr (Fig. 9). Two droughts that occurred in the middle-12th and late-13th centuries (centered on about AD 1155 and about AD 1285) are of particular interest as one or both occurred during the same time as population declines among the prehistoric Native Americans discussed above.

Tree-ring-based reconstructions of the Palmer Drought Severity Index (PDSI) (Cook et al., 2004), precipitation (Dean and Funkhouser, 2004), and discharge (Meko et al., 2001) indicate that intense and persistent drought occurred during the three periods associated with Native American population declines across much of the western United States (Fig. 10). An early-11th-century (AD 990-1060), a middle-12th-century (AD 1135-1170), and a late-13th-century (AD 1276-1297) drought impacted, respectively, ~50, ~58, and ~52% of the western US (Fig. 10a) (Cook et al., 2004). Whereas the latter two droughts impacted all records depicted in Fig. 10, the early-11th-century drought was not recorded in the northern Sierran record (Fig. 10f).

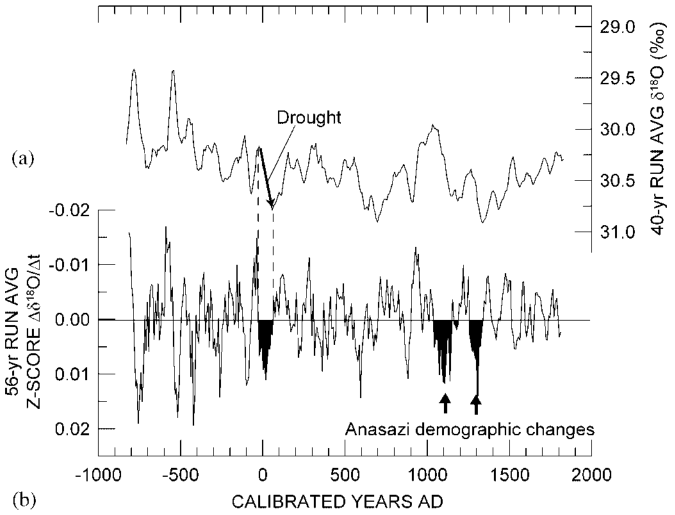

Fig. 9. (a) A 2630-yr δ^{18}O record for Pyramid Lake, Nevada. When δ^{18}O is decreasing the lake is rising and vice versa. The data have been smoothed with a 40-yr running average. (b) A 56-yr running average of the derivative of the δ^{18}O record from Pyramid Lake, Nevada. Droughts are defined as times when the derivative is positive. Data were taken from Benson et al. (2002). Vertical arrows point to the middle-12th- and late-13th-century droughts.

Tree-ring-based reconstructions of the mean value of the PDSI, for each of the three periods, provide a more-continuous measure of the areal extent of drought within the contiguous US (Fig. 1b-d). All three droughts affected most of the western US, and the AD 1276–1297 drought (Douglass, 1929) also appears to have substantially impacted the regions occupied by Mississippian Cahokians (Fig. 1c). Reconstructions of the areal extents of the early-11th- and middle-12th-century droughts (Fig. 1a, b) are less secure for the Midwest in that tree-ring records are generally lacking for that region and existing records become fewer the earlier the time frame of interest. Thus, the early-11th- and middle-12th-century droughts may have been more intense in the Cahokia area than what is depicted in Figs. 1a and b. In addition, drought severity is being integrated over relatively long time periods in Fig. 1

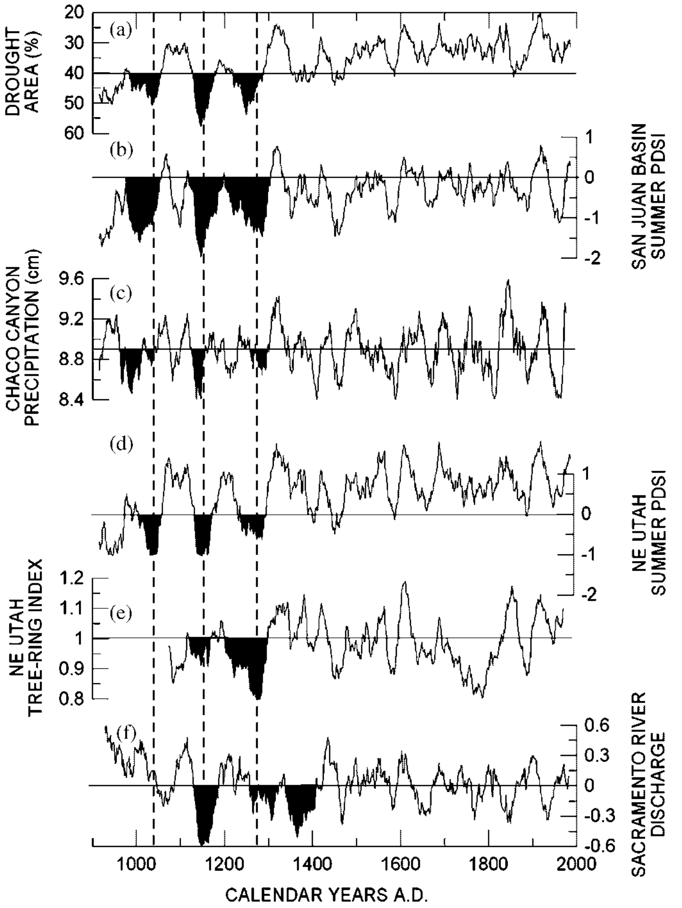

Fig. 10. Tree-ring-based climate reconstructions for (a) the western United States (Cook et al., 2004), (b) the San Juan Basin (Cook et al., 2004), (c) Chaco Canyon (Dean and Funkhouser, 2004), (d) northeastern Utah (Cook et al., 2004), (e) northeastern Utah (Stephen Gray, person communication, 2005) and (f) the Sacramento River (Meko et al., 2001). The black intervals connected by dashed lines indicate the early 11th-, middle-12th-, and late-13th-century droughts. All records have been subjected to a 31-yr running average. The northeast Utah data furnished by Stephen Gray consists of a composite growth index (all records normalized with mean-annual growth values set to 1) of 23 tree-ring chronologies from three sites. In the PDSI reconstructions, drought is considered to occur when PDSI <-1.

and, as such, the PDSI plots do not reveal the existence of intense droughts that may span only a few-to-several years.

4. Response of the Anasazi, Fremont, Lovelock, and Cahokian populations to drought

The three droughts discussed herein are multidecadal in length. In fact, the middle-12th- and late-13th-century droughts have been argued to have persisted for more than 100 yr in the western Great Basin (Stine, 1994; Benson et al., 2002) and have been associated with a 30–40% reduction in surface-water runoff to Mono Lake (Stine, 1990, 1998). We assert that droughts of this intensity and persistence severely impacted prehistoric human populations whether those populations were composed of hunter-gatherers or horticulturalists/agriculturalists, and that the impact was on water supply crucial to their prehistoric subsistence base(s).

4.1. Anasazi response to drought

In a recent paper, Benson et al. (2006a) reiterated the concept that severe droughts in the middle-12th and late-13th centuries (Fig. 10b, c) appear to have affected Anasazi populations in the Four Corners region. In the case of the Anasazi, a severe multidecadal drought would have strongly impacted maize agriculture, which over time had become the dietary staple of the Anasazi. In the early historical period, the Hopi and the Zuni descendents of the Anasazi attempted to keep a second year's supply of maize in reserve (e.g. Stevenson, 1904; Hough, 1915; Cushing, 1920) which would not have been sufficient to last through a multi-year drought. Annual consumption by the Hopi was ~12 bushels per person (Stephen, 1936) and the maize yield in a good year was ~12 bushels per acre.

Maize yields are a function of climate and the properties of the soil in which the maize grows. We do not know the environmental requirements of maize grown by the Anasazi; therefore, we must rely on the requirements of modern forage corn and maize grown by present-day Pueblo people as a proxy. We suggest that Zuni and Hopi agricultural practices are good analogs for Anasazi practices. During the historical period, maize was produced in areas that received 25 cm of annual precipitation or 15 cm of growing season precipitation (Shaw, 1988). However, optimum maize yields occur where growing season precipitation ranges from 40 to 60 cm (Minnis, 1981) and where the freeze-free period exceeds 120 days (Shaw, 1988).

Benson et al. (2006a), using freeze-free probabilities and precipitation data for 66 weather stations in the Four Corners region, determined the possible locations of areas in which dry-land farming of maize could occur, assuming that 90 freeze-free days and 30 cm of annual precipitation must be equaled or exceeded. Growing season precipitation averages ~50% of the annual precipitation in the 66 sites. They found that only 12 of the 66 sites have precipitation and freeze-free conditions that permit dry-land farming of maize and that the sites were on the periphery of the San Juan Basin. Therefore, modern climate, which is much wetter than past intervals of multidecadal drought, does not support dry-land farming within much of the region formerly occupied by the Anasazi.

Maize-based agriculture allowed the Anasazi to flourish during the decades prior to the middle-12th-century drought; however, the middle-12th-century drought resulted in the abandonment of most of the great houses in the central San Juan Basin (Fig. 2). During the subsequent late-13th-century drought, most of the remaining great houses and many of the smaller villages in the Four Corners region were abandoned (Fig. 2). The effect of the two droughts also is evident in the distribution of tree-ring-dated habitation sites which indicate rapid population declines starting at AD 1130 and 1280 (Fig. 3) (Berry, 1982). The drought that occurred between about AD 990 and 1060 in the San Juan Basin may have caused some Anasazi to leave Chaco Canyon and move north to the San Juan River area where they began construction of Salmon Ruin in AD 1068 with the erection of four rooms in the east wing of the ruin (Larry Baker, personal communication, 2005).

4.2. Fremont response to drought

Given the adaptive diversity of the populations in the Fremont area, their response to intense and sustained drought (Fig. 10d, e) may not have been as uniform as that of the Anasazi who probably were more dependent on horticulture but who also included hunter-gatherers during their residence in the Four Corners region. Intense drought would have engendered increased competition for limited resources between horticulturalists, hunter-gatherers, and between horticulturalists and hunter-gatherers, resulting in declining populations amongst all Fremont groups. In this sense, the Fremont may have been as dependent on horticulture as the Anasazi.

The overall population decline that began at about AD 1000 (Fig. 5), as well as the decline in northern Colorado sites documented by Massimino and Metcalfe (1999), may be attributable to the early-11th-century drought (Figs. 1a, 10a, d). Whereas the period AD 990–1060 appears to bracket a single drought in the PDSI constructions of the western US and the San Juan Basin (Fig. 10a, b), tree-ring constructions for individual sites surrounding the San Juan Basin, New Mexico, indicate the presence of one to three droughts within the same approximate (AD 970–1060) time interval (Fig. 4 in Benson et al., 2006a). This indicates that drought persistence during the late-10th and early-11th centuries varied spatially. In the following, we will, for simplicity, continue to refer to this time period as the early-11th century.

Data from the greater Uinta Basin area indicate a shift in horticultural intensity from the northern to the southern part of the area during the first part of the AD 990–1060 drought with a later decline in overall population commencing during the middle-12th-century drought (Fig. 7). The southern half of the Uinta Basin may have functioned as a refugium where Fremont farmers from various regions that suffered drought stress aggregated in response to increased competition brought on by drought.

Additional evidence of the impact of the middle-12th-century drought on Fremont horticulture has been provided by Coltrain and Leavitt (2002) who, in a study of bone-collagen stable-isotope ratios, showed that Fremont, living along the eastern shore of Great Salt Lake, ceased consumption of maize after AD 1150, presumably because of persistent crop failure. It, however, remains to be demonstrated how general this pattern was among other Fremont populations.

The late-13th-century drought occurred after the abandonment of the greater Uinta Basin area and, therefore, would appear to have little effect on population decline in that area. However, the late-13th-century drought appears to have forced abandonment of populations residing in other regions of Utah (Fig. 5) (Berry and Berry, 2003).

4.3. Lovelock culture response to drought

Because the Lovelock culture's subsistence base was largely tied to the productivity of isolated bodies of water, droughts that caused marshes, sinks and lakes to become saline or desiccate would have severely impacted the population's viability.

A tree-ring-based record of northern Sierran river discharge (Fig. 10f) and a δ^{18}O record of change in the volume of a lake (Pyramid Lake) fed by a Sierran river (Fig. 9) (Meko et al., 2001; Benson et al., 2002) indicate that both the middle-12th- and late-13th-century droughts impacted water bodies in the western Great Basin, although the late-13th-century drought seems to have occurred slightly later in the Sierras than elsewhere and is much less intense than the Sierran middle-12th-century drought (Fig. 10). The tree-ring record also indicates the existence of an additional severe Sierran drought between AD 1340 and 1410 that may have contributed to the movement of Lovelock groups.

We have recalibrated the ^{14}C dates of rooted tree stumps found in the Mono and Tenaya lake basins (Stine, 1994) using CALIB 5.01 (http://radiocarbon.pa.qub.ac.uk/calib/). The dates are from the outer part of the stumps and, therefore, indicate the time the stump was submerged by rising water (end of drought). We suggest that the stump data (Fig. 11) are consistent with the existence of the three droughts indicated in the tree-ring record (Fig. 10f), in that the most probable ranges of the oldest set of stumps overlap at about AD 1140, and the probability distributions for the younger set of ages indicate that trees may have been killed by rising water at about AD 1310 and about AD 1390.

Annual discharges of rivers draining the Northern Sierra Nevada are highly correlated ($R^2 \approx 0.9$; Benson et al., 2002); therefore, we can approximate relative changes in Truckee River and Carson River discharges (and to a lesser extent Humboldt River discharges, $R^2 \approx 0.6$) from tree-ring-based reconstructions of Sacramento River discharge. Such a reconstruction indicates that the discharge of the Sacramento River decreased, on average, by 19% during the middle-12th-century drought (Fig. 12). This value, which is 10–20% less than that calculated by Stine (1990, 1998), probably is an underestimate, given that tree-ring-based reconstructions tend to underestimate low-frequency climate variability. In any case, multiyear reductions of Sacramento River discharge (and, therefore, Carson, Truckee, and Humboldt river discharges) by 40–50% (relative to historic measured values) occurred frequently during the middle-12th-century drought (Fig. 12), and may

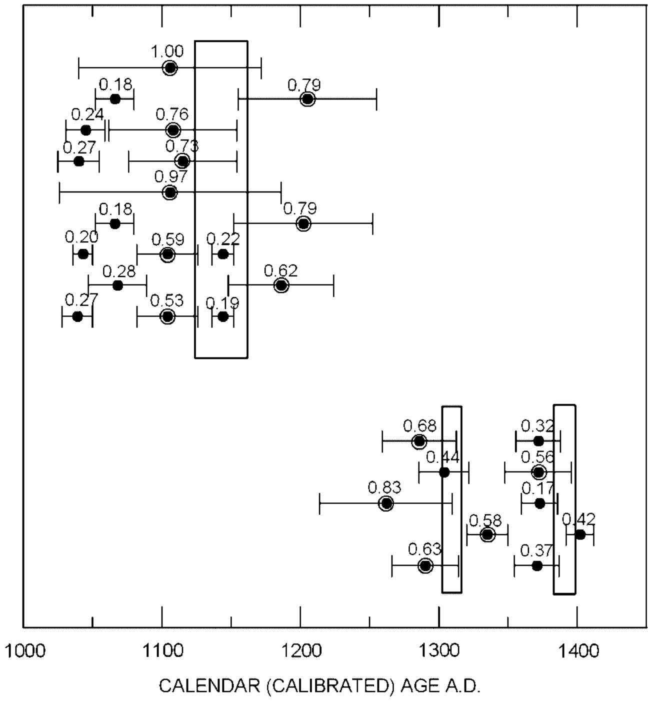

Fig. 11. Calibrated tree-stump dates from Mono Lake and Tenaya Lake, California. The ranges at the bottom of each set are from Tenaya lake. Probability of the 1-sigma range is given by the number over the symbol. Symbols surrounded by a circle indicate the highest probability range for a single calibration. Open rectangles surround times when trees were possibly killed by rising lake water.

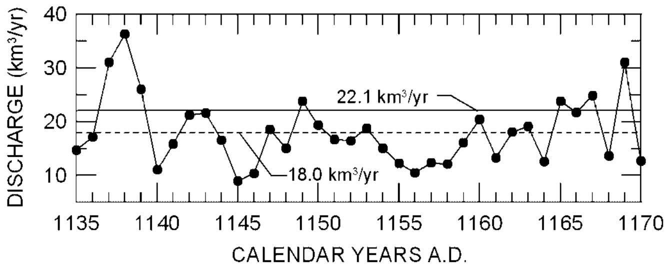

Fig. 12. Tree-ring-based reconstruction of annual discharge of Sacramento River during middle-12th-century drought. The reconstructed discharge of the river was $22.0 \pm 7.5\,\mathrm{km}^3/\mathrm{yr}$ between AD 701 and 1907 and it was $18.0 \pm 6.3\,\mathrm{km}^3/\mathrm{yr}$ between AD 1135 and 1170. Measured discharge between 1906 and 1997 was $22.1 \pm 9.5\,\mathrm{km}^3/\mathrm{yr}$.

have brought about the desiccation of Winnemucca Dry Lake as well as the Humboldt and Carson sinks. In any case, wetlands associated with the two sinks would have severely contracted, and in years when river discharge never reached the sinks, wetland plants may not have been able to establish themselves within the floodplains of the streams.

In the case of Lovelock foragers who utilized rock shelters near Winnemucca Lake, a multidecadal drought would strongly affect their lacustrine subsistence base. For example, if the droughts that caused Mono Lake to decline (Stine, 1994) also caused discharge to Lake Tahoe to decrease (on average) by ⩾30%, Lake Tahoe would have ceased overflowing, cutting off about one-third of the input to the Truckee River. Given that the other source of main-stem Truckee River discharge (the Little Truckee River surface-water system) also decreased by ⩾30%, the overall amount of water reaching Pyramid Lake would have been reduced by ⩾50% (Benson et al., 2002). If the drought persisted for 100 yr, Pyramid Lake would have declined ~67 m to a depth of 55 m and its salinity would have increased to ~16,000 mg/L. Under these conditions, the thermocline would have bottomed in Pyramid Lake, allowing the lake to mix vertically in the summer, releasing nutrients to the water column, increasing productivity. The lake would tend to become anoxic and the fishery would collapse because the fish would not be able to find water that was both cold and oxygen rich.

In addition, Pyramid Lake would cease overflowing to the Winnemucca Lake Basin, and evaporation would cause the level of Winnemucca to decrease by ~1.25 m/yr. Historically, Winnemucca Lake reached a maximum depth of 25 m (Benson et al., 2002; Fig. 8); thus a 20-yr drought would cause the lake to desiccate, resulting in a dramatic decrease in aquatic resource availability.

A decreasing water supply would also have affected the availability of drinking water during drought. During extended drought, the increased salinity of lakes and sinks would have rendered them unfit for human consumption; therefore, the Lovelock would have had to turn to freshwater springs. However, all springs in the Carson Sink and Humboldt Sink areas are located relatively high above the basin floor, indicating their moisture comes from local recharge; in addition, the aquatic macroinvertebrate communities associated with existing springs do not indicate the existence of perennial flow (Donald Sada, personal communication, 2006). During drought, these springs would have experienced decreases in moisture flux, and would have ceased flowing during the autumn months. Thus, moisture stress may have played an important part in the emigration of Lovelock populations.

The Penutian language family includes the three Maiduan languages—Maidu, Konkow, and Nisenan. Historically, groups speaking these three languages appear to have occupied land to the west of Washoe territory that extended north and south of Lake Tahoe. Shipley and Smith (1979) examined cognate retention in these three languages and concluded that Maiduan people came into California from the east in stages, first the Nisenan, then the Konkow, and lastly the Maidu, which apparently still occupied the Honey Lake area in the 17th century (Riddell, 1978). This suggests the possibility that Penutian-speaking Lovelock populations may have left the desiccated marshlands of the western Great Basin and migrated to California in a recurrent manner, during the middle-12th- and late-13th-century (or late-14th-century) droughts, possibly to former homelands or to the homelands of related tribes.

4.4. Cahokian response to drought

The PDSI contour maps indicate that only the late-13th-century drought impacted Cahokia (Fig. 1). However, the rise and fall of the late-Mississippian Cahokia complex parallels the rise and fall of the Anasazi, suggesting that the middle-12th-century drought may also have reached the Cahokia area. Both the Four Corners region and Cahokia were sites of intense growth between about AD 1050 and 1130. In Chaco Canyon, several new great houses were constructed and the existing greathouses remodeled. By AD 1150, both cultures were undergoing stress. Many of the Anasazi great houses and farming villages in the greater San Juan Basin were abandoned at this time, while, at Cahokia, surrounding farming communities were abandoned and defensive structures were being constructed. By AD 1300, both cultures had collapsed and their residual populations had left their homelands. Therefore, we suggest that the middle-12th-century drought did impact the Cahokia area and that the PDSI map of this drought fails to accurately indicate its true eastern extent.

5. Agricultural intensification and political power at Cahokia and Chaco

Building on earlier research (Judge, 1979; Marshall et al., 1979), we offer the hypothesis that agricultural intensification was the organizing principle that allowed the Anasazi and the Cahokians to increase their influence and exert political power over other tribal entities. That intensification probably resulted from the co-occurrence of a relatively benign climate and a leadership which understood that agricultural production could be increased on a massive scale. Such an understanding could have arisen within occupants of the Cahokia and Chaco areas or it may have been derived from immigrants who had previously experienced a different style of agriculture, applicable to the Cahokia and Four Corners regions.

In any case, resettlement of farmers that had occupied the northern Mississippi River floodplain accompanied the population explosion at Cahokia. Some of these farmers moved to new floodplain farms and others founded upland villages (Emerson 1997a, b). For example, the Richland farming complex and scores of smaller farming communities, were founded on the upland perimeter east of Cahokia beginning in about AD 1050.

Recent studies by Benson et al. (2003, 2006b) indicate that archaeological maize from the Pueblo Bonito great house in Chaco Canyon core area came from sites downstream of the canyon or from the Newcomb area at the base of the Chuskas. The Newcomb area also was the source of much of the timber (English et al., 1999), chert, and pottery (Toll, 1991) imported by Chacoan residents. The scale of the agricultural effort in Newcomb is indicated by field size which, in some cases, exceeded several square kilometers (Fig. 13) (Friedman et al., 2003).

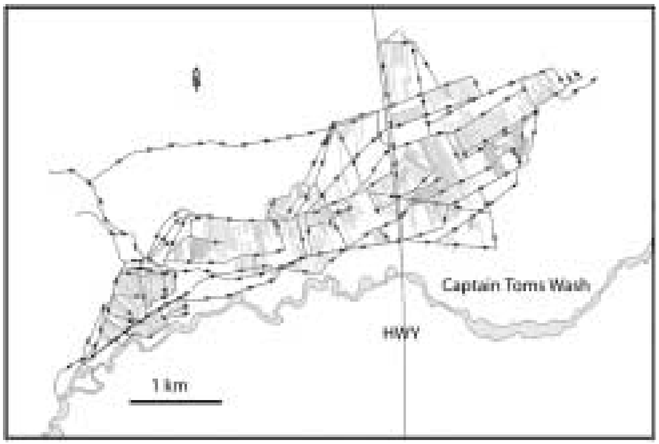

Fig. 13. Map of a Newcomb irrigated field area (adapted from Friedman et al., 2003). Light gray lines are internal field borders. Lines with arrows are irrigation ditches.

Thus, it would appear that both the Cahokians and the San Juan Basin Anasazi implemented agricultural intensification during times when climate permitted. However, the exploitation of the environment during relatively wet times left the expanded populations vulnerable to subsequent periods of intense multidecadal drought.

6. Climate forcing of droughts of the middle-12th and late-13th centuries

We have presented prima facie evidence that middle-12th- and(or) late-13th-century droughts possibly impacted some Native American cultures across much of the United States and that an early-11th-century drought impacted the Fremont and possibly the Anasazi (Fig. 1). Drought and its consequences (famine, reduced reproduction rate, war, and migration) all lead to population reduction. Even though those relying mainly on horticulture were more directly impacted by drought than hunter-gatherers, the impact likely was transferred to the hunter-gatherer through increased competition for existing resources.

Climatic change has previously been argued to be a major push factor in Anasazi and Fremont demographic change (e.g., Douglass, 1929; Berry, 1982; Lindsay, 1986; Coltrain and Leavitt, 2002). And some have argued that the collapse of Native American agriculture should be correlated with the onset of the Little Ice Age (LIA) which has been assumed to have begun at AD 1300 (e.g., Lindsay, 1986; Petersen, 1994; Pauketat, 2004, p. 28). We do not agree with that assessment.

Different climate-change parameters have been used to define the LIA, but the two most commonly invoked are glacier advance and decreased air temperature. However, neither of these parameters indicates a synchronous change of climate across the globe or northern hemisphere at AD 1300. While it is true that glaciers in the Swiss Alps began a series of advances about AD 1300, (Holzhauser, 1997; Grove, 2001a) previous advances of the same magnitude had occurred at AD 250 and 950. Thus major glacier advances in the Alps are not unique to the LIA. In addition, there were three principal ice advances between AD 1300 and 1850, indicating that climate during the LIA was not monotonic. Grove (2001b) has argued that radiocarbon and dendrochronologic dating of moraines indicates that the LIA was a synchronous global event; however, glaciers in the Altai, in the Canadian Rockies, and in temperate South America do not indicate advances in the late-13th or early-14th centuries (Grove 2001b, p. 178).

In terms of ice-core records, data from Siple Dome, West Antarctica and central Greenland indicate that meridional atmospheric intensity associated with the onset of the LIA began about AD 1400 (Kreutz et al., 1997).

In terms of LIA cooling, modern reconstructions of Northern Hemisphere temperature indicate that cooling began on or about AD 1100 not at AD 1300 (Jones et al., 1998; Mann et al., 1999; Crowley and Lowery, 2000; Briffa and Osborn, 2002). Major temperature minima occurred between AD 1600 and 1700 and between AD 1800 and 1850 with a local maximum in temperature at AD 1300 (Jones et al., 1998; Crowley and Lowery, 2000). Although indicating decadal-scale fluctuations in temperature, high-resolution tree-ring records from several areas around the globe do not indicate a LIA signal (Bradley and Jones, 1992). In fact, tree-ring-based reconstructions of southern Colorado-Plateau temperatures indicate that it was anomalously warm, not cold, during the middle-12th- and late-13th-centuries (Fig. 14b; Salzer and Kipfmueller, 2005). Positive temperature anomalies also have been documented in the southern Sierra Nevada for the same time intervals (Graumlich, 1993). Therefore, major reductions in prehistoric Native American habitation sites/population occurred during anomalously warm, not cold, climatic phases.

Not only was it relatively warm during Native American reorganizations that occurred in the middle-12th- and late-13th centuries, the middle-12th-century reorganization began 150 yr prior to glacier advances associated with the LIA in northern Europe (Grove, 2001a). The habitation data presented above indicate that it was the middle-12th- not the late-13th-century drought that had the strongest impact on the Anasazi and Mississippian Cahokia cultures. By AD 1150, the Anasazi had abandoned 85 percent of their great houses in the Four Corners region and most of their village sites (Figs. 2, 3), and the Cahokians had abandoned one or more of their agricultural support centers, including the large Richland farming complex (Alt, 2001; Pauketat, 2004). In addition, the sedentary Fremont appear to have abandoned many of their southern area habitation sites in the greater Uinta Basin area by AD 1150 (Fig. 7) as well as the eastern Great Basin and the Southern Colorado Plateau. Fremont populations in the eastern Great Basin began to decline at AD 1150 (Massimino and Metcalfe, 1999). In some sense, the 13th-century drought may have simply "finished off" some cultures that were already in decline.

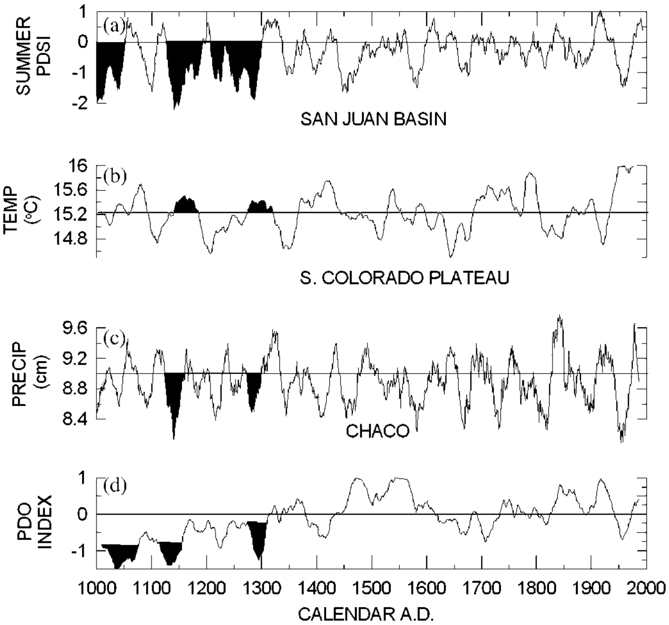

Fig. 14. Tree-ring-based climate reconstructions for (a) summer PDSI for the San Juan Basin (Cook et al., 2004), (b) temperature in the southern Colorado Plateau (Salzer and Kipfmueller, 2005), (c) precipitation in Chaco Canyon, New Mexico (Dean and Funkhouser, 2004), and (d) the Pacific Decadal Oscillation (MacDonald and Case, 2005). The black areas indicate changes in climate that accompanied the middle-12th- and late-13th-century droughts. All records have been subjected to a 21-yr running average.

Although the droughts on which this paper focuses cannot be linked to the LIA, they can be linked to the Pacific Decadal Oscillation (PDO) in that both droughts occur during minima of the PDO (Fig. 14a, c, d). The PDO has a spatial pattern similar to the El Niño Southern Oscillation (ENSO) (Mantua et al., 1997); i.e., during positive phases of the PDO, the southwestern US tends to be wetter than average and during negative phases of the PDO the southwest tends to be dry. A positive PDO phase is associated with warmer-than-normal temperatures in the eastern equatorial Pacific Ocean and cooler-than-normal temperatures in the northwest Pacific Ocean. However, the PDO has a very different time signature, having a pseudo-cyclicity ranging from 50 to 70 yr (MacDonald and Case, 2005), whereas typical ENSO events occur every 4–7 yr and persist from 6 to 18 months.

Benson et al. (2006a) have shown that, for the period of record, a negative PDO interval is characterized by reduced water-year (October 1–September 31) and summer (June, July, August) precipitation in the San Juan Basin area. This suggests a weakening of both winter cyclonic and summer monsoon systems in the southwest during a negative PDO.

Enfield et al. (2001) have demonstrated that reduced precipitation in the Mississippi Basin and in the American West (except for the Pacific Northwest) was strongly correlated with a positive AMO (Atlantic Multidecadal Oscillation) for the period of record (AD 1860-present).

The AMO is an index of detrended SST anomalies that are averaged over the North Atlantic Ocean from 0 to 60° or 70° N (Kerr, 2000). The detrended AMO index has been associated with multi-year precipitation anomalies over North America, and it has been shown to influence summer precipitation over the United States (Enfield et al., 2001). During the instrumental period (1856–2005) it has exhibited a 65-to-80-yr pseudo cycle. Recently, McCabe et al. (2004) demonstrated that, during the past century, drought frequency for all areas discussed in this paper was greatest when a negative PDO occurred during a positive AMO. In addition, Benson et al. (2006a) have shown, using tree-ring-based reconstructions of the AMO and PDO, that five of six southwestern droughts that occurred during the past 300 yr were associated with a negative PDO and a positive AMO. We therefore suggest that the middle-12th- and late-13th-century droughts were associated with a climate regime characterized by a negative PDO and, possibly, a positive AMO.

7. Summary and conclusions

We have examined evidence of the decline of four prehistoric Native American groups: the Anasazi, the Fremont, the Lovelock, and the Mississippian Cahokians. Three of these groups, the Anasazi, the Fremont, and the Cahokians relied on horticulture as a principal part of their subsistence base. Maize was the staple food of the Anasazi. Horticulturalists and hunter-gatherers occupied the Fremont region. Maize was an important part of the diet of the Cahokians; however, they lived in a relatively productive area and had at their disposal a relatively wide range of energy-rich flora and fauna. Agricultural intensification was the most prominent alteration of the Mississippi valley during the Cahokian expansion and that may also have been true for the Anasazi and the Fremont who occupied, respectively, the Four Corners region and Utah. The Lovelock were hunter-gatherers who relied heavily on flora and fauna found in western Great Basin marsh environments. Thus, each of these groups relied on, to a greater or lesser extent, resources which were precipitation dependent.

Little or no data exist with respect to Lovelock population dynamics other than the intensive use of caves for caching material culture when compared with preceding and subsequent occupations. However, it would appear that the introduction of horticulture allowed the populations of the other groups to swell during times of abundant precipitation. In fact it might be argued that, not unlike existing nation states, these people did not encourage a memory of bad times but allowed their populations, in good times, to expand to the limit of their resource base.

In terms of construction projects, the Anasazi and the Cahokians evince some rather amazing parallels. Between AD 1050 and 1130, accelerated great-house construction occurred across the Four Corners region, including six new great houses in Chaco Canyon. By AD 1130, over 207 great houses populated the Four Corners region (Fowler and Stein, 1992). During approximately the same period, the Cahokians constructed over 120 pyramidal mounds and increased their residential population by a factor of about five within a 1.8-km^2 area (Pauketat, 2004). The population in the vicinity of Cahokia may have reached 50,000 people (Pauketat, personal communication, 2006).

The precipitation-dependence of these groups appears to have brought about their demise. In the early 11th-century (AD 990–1060), much of the US west of the Mississippi experienced a severe drought (Fig. 1a) that impacted the Fremont population. This drought also impacted the San Juan Basin and may have been responsible for the emigration of some individuals from Chaco Canyon to the better-watered San Juan River area where they began construction of Salmon Ruin great house in AD 1068.

In the middle-12th century, an intense and persistent drought affected much of the contiguous United States. It is not known how severe the drought was in the Cahokia area because tree-ring chronologies are sparse in the Midwest (Fig. 1b). This drought led to massive Anasazi and Fremont habitation-site declines; e.g., 85 percent of the great houses in the Four Corners region were abandoned (Fowler and Stein, 1992) and some of the Fremont horticulturalists left the Tavaputs Plateau. By this time, the Cahokians had abandoned one or more of their agricultural support centers, including the large Richland farming complex, suggesting that the middle-12th-century drought did, indeed, impact the Cahokia region. We have no data on the response of the Lovelock to the middle-12th-century drought; however, during the subsequent late-13th-century drought, the remnants of all four cultures appear to have abandoned their former homelands. In some sense, the two droughts acted as a slow-motion, one-two punch with the first blow putting the cultures on their knees and the second blow ending the fight.

Acknowledgments

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