Summary of Dissertation Research

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Introduction

This document outlines dissertation research that examines the interplay between prehistoric population dynamics and paleoenvironment, and to what extent these factors influenced culture change over the last 2500 years on the western High Plains of Colorado. The population dynamics of prehistoric hunter-gatherers in eastern Colorado are estimated using several proxies, including the summed probability distribution of radiocarbon ages from archaeological sites in eastern Colorado. The paleoenvironment of the High Plains is reconstructed in the multi-proxy records derived from the sediments of “pocket fens,” small wetlands that have proven to contain at least decadal resolution sedimentary records of paleoenvironment extending into the middle Holocene. Well-dated, high-resolution records of paleoenvironment are important because they allow a more detailed examination of the complex relationship between climate, population and culture change. These records from pocket fens not only document extended periods of high amplitude deviations in climate (such as drought) that could have influenced cultural adaptations, they also document periods of high temporal variability in proxy temperature and effective moisture that could have disrupted existing cultural systems. Periods of high temporal variability in climate would result in lower predictability of environment-dependant resources on an annual and decadal temporal scale, which in turn may have exceeded the inherent resiliency of cultural adaptations available within the knowledge base of these systems. Episodes of drought and high temporal variability of environmental conditions are both coincident with periods of culture change in the archaeological record for eastern Colorado.

Although the archaeological record of eastern Colorado documents cultures that are far from static, this research focuses on two periods of particularly rapid culture change. The first is the transition between the Late Archaic and Early Ceramic periods seen ca. AD 100-200 in eastern Colorado. This transition is characterized by many of the technological, economic and social innovations that are almost universally associated with the shift between Archaic and Formative cultural patterns. The second is the transition between Early Ceramic/Developmental period (ca. AD 100-1100) and the Middle Ceramic/Diversification period (ca. AD 1100-1540). This latter period was characterized in the Platte and upper Kansas River Basins of northeast Colorado by increased mobility and population dispersal and in the Arkansas River Basin of southeast Colorado by increased sedentism and population aggregation initially, followed by dispersion and out migration. The cultural data for this research are derived primarily from the prehistoric contexts for the Platte River Basin, which includes the upper Kansas River Basin (Gilmore et al.1999) and the Arkansas River Basin (Zier and Kalasz 1999). The paleoenvironmental data are taken from analysis of sediment cores from pocket fens in eastern Colorado (Gilmore 2006; Gilmore and Sullivan 2006a, 2006b; Gilmore and Sullivan 2007) (Figure 1).

Identification of the Problem

The relationship between climate change, prehistoric population and culture change is a topic that is of great interest to archaeologists, geographers and environmental scientists, and the relationship between these variables is complex. Culture change has often accompanied climate change, and although cultural systems are dynamic and adaptive, there are also many examples of prehistoric population decline, dispersion and/or migration that coincide with
climatic deterioration. This suggests that in some circumstances changes in culture in response to changes in climate are insufficient to maintain in situ population levels. Although we do not argue for a deterministic relationship between population and environment, it is arguable that climate change can provide the impetus for many changes seen in the archaeological record, including changes in population size, density and distribution, and changes in cultural adaptations (Brenner et al. 2001; Gill 2000; Jones et al. 1999; Weiss and Bradley 2001).

As well as being influenced by climate, population increase also has its own momentum, and modeling the introduction of new species (including humans) into a previously unoccupied territory suggests that population growth can approximate an exponential function; it is initially slow, with more rapid growth occurring once the landscape contains sufficient population density to provide the optimal combination of available territory and mate availability (Fix 2002; South and Kenward 2001). Ultimately, population growth is constrained by resource availability and carrying capacity. In order to address the effect of population dynamics and climate on culture in prehistory, proxies for population and paleoclimate need to be developed. The sedimentary records from “pocket fens” meet the need for a source of continuous records of paleoclimate on the plains, and the methods for deriving these records are described in the following sections. This leaves perhaps the more difficult task of developing population proxies for hunter-gatherers. The following section outlines a method that has explanatory value.
Estimating the Population of Hunter-Gatherers in Eastern Colorado

Estimates of prehistoric hunter-gatherer population are rarely attempted for several reasons. Unlike populations of sedentary people for whom momentary population estimates can be made based on the floor-areas of contemporaneous habitations and dated to a narrow time period using ceramic chronologies, hunter-gatherer groups are often highly mobile, and their impact on the landscape is ephemeral. The consequent meagerness of the archaeological record of these people coupled with the less precise chronologies derived from radiocarbon ages renders momentary estimates of their population difficult by standard methods. The few attempts that have been made to measure the population of prehistoric hunter-gatherers have met with mixed results. Measures of prehistoric human population based on environmental factors, such as carrying capacity derived from estimates of the biomass for a given environment, are a useful starting point (i.e. Hassan 1981). However, these models only provide a measure of the potential population of a given environment, and make assumptions about both cultural adaptations and resource use that are almost always difficult if not impossible based on archaeological data, and also assume that environment and culture are static. These mathematical methods strive to derive precise population number for a given region and usually result in a predicted range of population so large as to be of little practical use, or a specific figure that is impossibly precise (see Upham 1992). Yet even if the derivation of actual population numbers is beyond current methodologies, we believe that proportional changes in prehistoric hunter-gatherer populations can be determined by several methods.

The number of archaeological components cross-dated to a particular cultural-historical period has been used widely as a rough measure of relative size of population, and the frequency of radiocarbon dates through time has also been used as a more detailed indicator of the relative size of population or intensity of occupation in large areas (Chatters 1995; Gilmore et. al. 1999, Prentiss et al. 2005; Reed and Metcalf 1999, Zier and Kalasz 1999). We recognize that issues of site formation, differential preservation of landforms and research bias in a particular geographic area could potentially skew these data. However, the large size of the regions investigated and the resulting wide variety of depositional contexts (fluvial, eolian and colluvial) within mountain, foothills and plains environments represented, coupled with the large number of sites recorded during cultural resource management projects (which document all of the sites within a specific project area) militate against these biases. Even taking all of these issues into consideration, archaeologists recognize that the number of components recorded for a certain period of time in a large area does in some way reflect the number of people who lived in an area at that time. Based on this measure, archaeologists have hypothesized an increase in population in eastern Colorado between the Late Archaic period (ca.1000 BC-AD 150) and the Early Ceramic period (ca. AD 150-1150) in the Platte Basin and the Developmental period (ca. AD 100-1050) in the Arkansas Basin. This increase in population culminates at the end of the Early Ceramic period in the Platte Basin, but continues through the Developmental period and into the Diversification period (AD 1050-1450) in the Arkansas Basin (Figure 2). However, since the length of different cultural periods varies widely, the number of components cross-dated to a given period is not directly comparable to the number for any other period unless these counts are normalized using the amount of time covered by each period, using the Index of Occupational Intensity (number of components in a period divided by the length of the period multiplied by 1000) (Larmore and Gilmore 2006). Graphing the IOI by period within the prehistoric cultural chronologies of the Platte and Arkansas River Basins of eastern Colorado supports what archaeologists have suspected, that the number of components increases through time and peaks in the Early Ceramic period in the Platte Basin and in the Diversification Period in the Arkansas basin. This result is
somewhat at odds with the distribution of uncorrected radiocarbon dates for the Arkansas Basin, which indicates a peak in population toward the end of the Developmental period (Figure 2).

![Figure 2](image)

Figure 2. Distribution of prehistoric radiocarbon ages (number of intercepts per century) in the plains sub-region of the Platte and Arkansas River basins, with number of components and Index of Occupational Intensity (IOI) per cultural period. Data compiled from Gilmore et al. (1999) and Zier and Kalasz (1999).

These different lines of information suggest an increase in population after the Late Archaic period in both basins, and a subsequent drop in population after the Early Ceramic period in the Platte Basin and the Diversification period in the Arkansas Basin. However, due to the length of cultural periods, the level of resolution of IOI data is so low that it has limited utility in determining the nature and structure of this hypothesized increase and decrease, and the
distribution of uncorrected radiocarbon dates seems at odds with the component data, showing a drop in proxy population in the Developmental Period rather than in the Diversification period.

Using the summed probability distribution of calibrated radiocarbon dates as a proxy for population dynamics has an advantage over these methods. Although not a representation of actual population numbers, the summed probability distribution associated with the set of calibrated radiocarbon dates from archaeological sites in the Platte and Arkansas basins does provide a visual representation of the rise and fall of population and/or occupational intensity; the higher the peaks in the curve, the higher the probability contributed by radiocarbon ages from dated features created by prehistoric people. The resulting aggregated probability curves serve as a high-resolution proxy for relative size and concentration of prehistoric population for a given area (Figure 3). However, the nature of the calibration curve suggests that some caution should be exercised with this method. As a result of fluctuating concentrations of atmospheric $^{14}$C through time, the calibration curve is not a straight line, but a series of peaks and valleys that document these fluctuations. As a result, some of the lower amplitude peaks and valleys on the population proxy curve are artifacts of the calibration and not a reflection of population dynamics. For example, “wiggle matching” (Ramsey et al. 2001; Mauquoy et al. 2001) the summed probability curves to the radiocarbon calibration curve makes obvious some of these artifacts. This is especially obvious in the summed probability curve for the Arkansas Basin after AD 1300 (and to a lesser extent the curve of the Platte Basin for the same time period), which reflects the calibration curve rather closely. There are also several flat sections of the calibration curve that are reflected in the summed probability distribution curves for both basins (Figure 3). However, the larger trends do not reflect the calibration curve and these higher amplitude changes are the ones that document population. Gamble et al. (2005) and Shennen and Edinborough (2007) all point out that these curves are remarkably stable, and maintain the same general shape even when curves are generated from large random samples of radiocarbon dates from a particular region.

![Figure 3. Summed probability distributions of archaeological radiocarbon ages (proxy population) for the Platte and Arkansas River Basins, compared to the radiocarbon date calibration curve (Stuiver and Reimer 1998).](image)
Calibration of radiocarbon ages and the generation of summed probability distribution curves for this study was accomplished using the shareware program CALIB version 5.0 (Stuiver and Reimer 1993; Stuiver et. al. 1998). Summed probability distribution curves generated from radiocarbon dates have been used elsewhere as proxy measures of the relative size of prehistoric populations, but the focus of most of these studies were relatively small geographic areas such as a portion of the Southern Rocky Mountains in Colorado (Benedict 1999), the so called “Vacant Quarter” of the lower Ohio River Valley (Cobb and Butler 2002) and the southern coast of British Columbia (Lepofsky et al. 2005). The studies of larger regions have to date focused on late Pleistocene to middle Holocene populations in Europe (Gamble et al. 2005; Shennan and Edinborough 2007). All of these studies stress the relative nature of this method as an indicator of population trends, and not representing actual numbers.

Focusing on the last 2900 years in the Platte and Arkansas basins, the summed probability curves of calibrated radiocarbon curves for both areas suggest that some changes in population were in phase during this period, while some changes were out of phase (Figure 3). These data reflect the same patterns observed above, but deliver it at a level of resolution that allows for a more detailed examination of the record. An increase in summed probability at the transition between the Late Archaic and the Early Ceramic/Developmental periods ca. AD 1-200 suggests that population increase may have contributed to the adoption of the technological innovations and social restructuring (adoption of the bow and ceramics, among others) that characterize the Archaic/Formative transition in Colorado. After approximately 800 years of population increase, proxy population peaks in the Platte Basin ca. AD 1000-1150. This comes at the end of the Early Ceramic period, which is characterized in the archaeological record by increased sedentism, larger group size and limited evidence of incipient corn horticulture. A relatively precipitous decrease in population follows this peak into the Middle Ceramic period (AD 1150-1540), which is characterized in the archaeological record by evidence of smaller more ephemeral sites indicative of a more dispersed and mobile population (Brunswig 1996; Gilmore 1999). Proxy population peaks somewhat later in the Arkansas Basin (ca. AD 1200-1300) in the middle of the Diversification Period (AD 1050-1450). This period is characterized by a general trend toward increased sedentism and more substantial and clustered habitation structures, limited corn agriculture and aggregation of Apishapa phase populations in larger village sites (some of which were fortified) (Kalasz et al. 1999). The current research proposes to examine how population dynamics in the Platte and Arkansas basins effect culture change in each area, and to examine how the patterns in proxy population and archaeological data suggest interaction between the Platte and Arkansas basins.

Along with population, climate change has been demonstrated to influence culture. Archaeologists have long posited the influence of climate on culture change in eastern Colorado and the Great Plains in general (Brunswig 1996; Wedel 1986; Tate and Gilmore 1999). However, due to the lack of records of paleoclimate specific to the plains, records from the periphery have been used to extrapolate into the heart of the plains. The records from pocket fens provide continuous records of paleoclimate that is far superior to other sediment records available for the High Plains, these records exceed the temporal depth of tree-ring records available for the plains and pocket fens are apparently far more common than other sources for continuous records.
Based on relative measures of proxy population, a period of population growth in eastern Colorado begins just prior to the transition between the Late Archaic and Early Ceramic/Developmental periods, which is defined archaeologically by the adoption of technological innovations such as ceramics and the bow and arrow. During this period population increase seems to lead culture change. After this initial increase in population there is a flat segment or slight dip in the proxy population curves for both basins that is thought to be an artifact of the radiocarbon calibration curve. Subsequent to this flat spot, there is a period of sustained and rapid population increase that begins ca. AD 500 and peaks for 300 years (AD 1000-1200) in the Platte Basin and for approximately 200 years (AD 1200-1300) in the Arkansas Basin (Figure 3). Coincident with population growth after AD 500, there is also an increase in evidence in the archaeological record for sedentism and intensification of the use of wild resources, and toward the end of the sustained peak in population (AD 1100-1200) corn becomes much more common in the archaeological record in both basins.

Many theories seeking to explain how the change from hunting and gathering to food production occurred are a variation on a theme, explaining origins and subsequent intensification as a response (at least in part) to population pressure (Binford 1968; Boserup 1965; Cohen 1977; Hayden 1995), or population “packing” within environmentally or socially circumscribed areas (Binford 1983). Theories that posit other factors such as climate changes as the mechanism and population increase as the effect of domestication (e.g. Richerson et al. 2001) rely on mathematical models of population growth unfettered by factors that would militate against exponential rates of natural increase at low population densities such as mate scarcity (South and Kenward 2001) and the effects of high mobility (Fix 2002).

Population appears to decrease rapidly after AD 1200 in the Platte Basin, and this decrease is coincident with the transition from the Early Ceramic to the Middle Ceramic period, which as discussed above is characterized by changes in material culture (replacement of corner-notched points with side-notched forms and replacement of Plains Woodland-like ceramics with those resembling Plains Village types) and an apparent reduction in the number of sites and generally less occupational debris at most sites, which has been interpreted as representing occupation of the Platte Basin by smaller, more mobile groups (Brunswig 1996; Gilmore 1999). In the Arkansas Basin, there is an even more precipitous drop in population that begins just before AD 1300 (Figure 3). The 14th century is characterized by the abandonment of the larger (and in some cases, defensive) sites and a dispersal of population, which culminated in the complete abandonment of eastern Colorado by the Apishapa by about AD 1450 (Kalasz et al. 1999). Some lines of evidence suggest that Apishapa populations may have moved to the east and south where they were eventually incorporated into Caddoan groups (Grinnell 1961; Gunnerson 1995; Schlesier 1994).

Based on the population proxies developed for eastern Colorado, there does appear to be a relationship between population proxies and culture change during prehistory in eastern Colorado. However, the mechanisms leading to culture change are apparently quite different depending on whether population is increasing or decreasing. An apparent increase in both basins that began several hundred years before the transition between the Archaic and Late Prehistoric suggest that population increase may have contributed to this change in culture, and subsequent increases in population during the Early Ceramic/Developmental period may in turn have contributed to the adoption of limited agriculture in both basins. In these two situations, population increase apparently preceded the adoption of technological innovations that contributed to increased efficiency in resource utilization or introduced new subsistence strategies and decreased mobility, which fits the model of population as a forcing mechanism for technological innovation. However, the rapid
decrease in population in both basins is either coincident with or post-dates innovations that mark the transition to the Middle Ceramic/Diversification period, suggesting that some other factor is the forcing mechanism pushing population decrease, not the other way around. Whether 13th-14th century population decline indicates migration out of the area or in situ decrease is unknown at this time. Although it has been suggested that the Apishapa abandoned eastern Colorado after AD 1300, it is possible that part of what occurred was an in situ population reduction, which could have occurred relative rapidly with only modest changes in total fertility and morbidity (Hill et al. 2004). Whether decrease in resident population or out migration, this shift indicates a loss of stability in the existing social and economic systems of both societies that lead to fundamental reorganization at relatively lower levels of complexity. This suggests that outside influences such as environmental change may also contribute to cultural reorganization.

If the summed probability curves are accepted as proxies that reflect the trends in prehistoric population, then the relationship between climate change and periods of demographic and cultural reorganization in eastern Colorado can be critically examined using the records of paleoclimate derived from the analysis of the pocket fen sediments (Figures 4 and 5). Based on the preliminary results, the transition between the Late Archaic and Early Ceramic periods in eastern Colorado occurs during a period of low transmittance and high organic content dated 50 BC-AD 375 and designated here as the “Terminal Archaic Drought.” In addition to drought conditions, this period is also characterized by high variability in both temperature and effective moisture proxies. This high climatic variability, in conjunction with drought, occurring concurrent with increasing population would have provided a forcing mechanism for the technological changes observed in the archaeological record that define the transition between the Archaic and Formative stages in Colorado. Periods of apparent sustained population growth in both basins ca AD 500-650 correlate with a period of increased effective moisture, decreased temperature, and decreased climate variability. A drop in population in both basins occurs during the initial centuries of the Little Ice Age. Although this is a period of increased effective moisture and decreased temperature, it is also a period of high variability in both of these proxies. It is unknown if this is a factor in population decline.
Figure 4. The temperature record (Percent organic matter, expressed as %OM) for fens in eastern Colorado correlated to paleoclimatic events. The record from Chico Creek 2 does not reflect the Medieval Climate Anomaly signal present in the other records. Lighter colors represent values above and below the mean, darker colors represent deviations from mean values greater than one standard deviation in magnitude. Red diamonds indicate location of AMS dates.
Figure 5. The effective moisture record (Percent transmittance divided by grams organic matter, expressed as %T/OM) for fens in eastern Colorado correlated to paleoclimatic events. Humification analysis was not performed on the sediments from Chico Creek 1 due to the low organic content of the sediments. The record from Chico Creek 2 does not reflect the Medieval Climate Anomaly signal present in the other records. Lighter colors represent values above and below the mean, darker colors represent deviations from mean values greater than one standard deviation in magnitude. Red diamonds indicate location of AMS dates.

**Paleoclimate Proxies from Pocket Fens**

As mentioned above, the sediment records recovered from pocket fens distributed throughout the western High Plains can supply the sort of high-resolution paleoenvironmental data necessary to examine prehistoric population and adaptation in detail. A multi-proxy approach allows for data not only to be cross-checked, but multiple lines of evidence of temperature, effective moisture and the response of vegetation communities to these changes allows for a more valid and nuanced interpretation of past conditions.

My dissertation research investigates the records of paleoenvironment contained within the sediments from “pocket fens,” which are small (25-2500 m³), inconspicuous features on the landscape (Figure 6). Partly because of their small size, they are subject to high rates of sedimentation (0.04-0.5 cm/yr), which provides decadal to sub-decadal resolution
paleoenvironmental records. The pocket fens so far investigated have contained 135-400 cm of peat and organic sediment, which have provided continuous records of effective moisture and relative temperature that extend to the middle Holocene (ca. 8000 BP). The discovery of pocket fens as sources of paleoenvironmental information overcomes several obstacles to examining long term climate change on the western High Plains, such as the general lack of paleoenvironmental data sources specific to the plains, and the inherent limitations of those that are available.

Figure 6. Looking north at Chico Creek 2, a pocket fen at the Pueblo Chemical Depot locality (Don Sullivan for scale). The area of green vegetation delineates the surface of the fen, which is approximately 40 m² in area.

Paleoenvironmental records previously available for the plains include tree ring records, which are sources of very high-resolution (annual scale) continuous records of paleoenvironment. However, records within the margins of the plains are extremely limited in their spatial distribution and temporal depth (Cook et al. 2004; Cook et al. 1999; H. Weakly 1962; W. Weakly 1971; Woodhouse et al. 2002). Fluvial and eolian sediment records can yield valuable information on past conditions, especially episodes of drought (Daniels and Knox 2005; Forman et al. 2001; Madole 1995, Mason et al. 2004), but due to the discontinuous nature of depositional processes and loss of portions of the record due to erosion, these proxies rarely reflect a complete record of past conditions. Recent studies using data from low elevation lakes on the Northern Plains (i.e. Fritz et al 1993, 2000; Laird et al. 1996) demonstrate that these features preserve continuous records of climate change. Unfortunately, perennial lakes do not exist on the semi-arid High Plains, and so continuous sediment records were thought to be unavailable for this area prior to the investigation of pocket fens.
In contrast to other sedimentological sources for paleoenvironmental proxies, all classes of mires such as bogs (ombrotrophic, or precipitation fed peatlands), fens (minerotrophic, or groundwater fed peatlands) and marshes (fens with grass cover over a mineral versus organic substrate) provide an environment in which sediments accumulate continuously over time (Charman 2002; Chambers and Charman 2004). The physical, chemical and biotic characteristics of these sediments reflect the environmental conditions under which they were deposited, thus providing a proxy record of local and possibly regional environment over thousands and in some cases over ten thousand of years. Until now, most research has focused on records of paleoclimate derived from the sediments of bogs found in northern latitudes (Blackford and Chambers 1991, 1993; Langdon and Barber 2004, 2005; Roos-Baraclough et al. 2004) or high elevation in western Colorado (Sullivan and Gilmore 2005; Sullivan, Taylor and Williams 2004; Taylor 2003, Williams 2005). Like larger peatlands, analysis of sediments from pocket fens suggests they also contain high quality archives of paleoenvironmental data (Gilmore 2006; Gilmore and Sullivan 2006; Sullivan and Gilmore 2005, 2006a, 2006b).

Obviously, the investigation and understanding of the lower elevation paleoenvironments of the plains and their response to changing climate would be greatly enhanced with data that was collected directly from low elevation sources. To this end, sediment cores were obtained from several small fens in eastern Colorado. Cores were collected at the U.S. Army Pueblo Chemical Depot (PCD) and the Chico Basin Ranch localities in the Arkansas River Basin, the Dyson Ranch locality in the headwaters of the South Fork of the Republican River, and the Pawnee Buttes and East Colfax Avenue localities in the South Platte River Basin (Figure 1).

Based on correlations to other proxies of paleoclimate, it becomes clear that the sediments within pocket fens characterize the environmental conditions under which they formed, and these conditions reflect both local environments and regional changes in paleoclimate. These records contain evidence of hemispheric and continental scale episodes of climate (i.e. the Medieval Warm Period and the Little Ice Age) as well as apparently smaller regional and local scale deviations (i.e. the Terminal Archaic Drought). The resolution of these records is high, and at a one centimeter sampling interval each sample represents between 23 years per sample and less than 4 years per sample, with the majority of samples representing around 10 years per sample. These high resolution records contain signals representing both high and low frequency climate events and provide records of past climate dynamics that extends beyond the temporal and response ranges of other proxies available for the Great Plains, which makes them ideal for determining the influence of climate on prehistoric population dynamics in eastern Colorado. As an example of the resolution of the climate record contained in pocket fens, a short duration period of significantly decreased transmittance (lower effective moisture) that occurs during the Little Ice Age is dated AD 1290 (Figure 5), and is believed to represent the late 13th century drought that was concurrent with the apparent abandonment of the Four Corners area by the Ancestral Puebloans (Lipe and Varian 1999). Although this episode does not compare to other episodes of significant decrease in effective moisture (for example, the Medieval Climate Anomaly), it is a significant decrease relative to the record before and after, and does correspond to the initial precipitous drop in proxy population in the Arkansas Basin and the continuing drop in population in the Platte Basin.

Comparison of population dynamics and paleoclimate requires very close chronological control of the pocket fen records, particularly when considering the less than 100-year difference in depopulation between the Platte and Arkansas basins ca. AD 1200-1300. This difference could be related to the timing of the onset and severity of the effects related to the Little Ice Age in the different basins, the relative severity of the late 13th century drought in the Arkansas, or could be related to differences in cultural response. Additional dates for the Arkansas Basin paleoclimate
records as well as dates for the Kansas Basin (Dyson Ranch) and Platte Basin (Pawnee Buttes) records are necessary to determine the nature of climate change along a north-south transect through eastern Colorado.

Although percent corrected transmittance (%T/OM) and percent organic material (%OM) are relative measures of effective moisture and temperature, we believe that with the very close chronological control provided by lead-210 dates, we may be able to correlate the physical characteristics of the sediments in the upper portions of the record with the historic instrument records of temperature and precipitation, and this way produce a more objective record of climatic conditions from the fen cores. Comparisons of the amount and seasonality of precipitation and historical records of spring discharge from small springs similar to those that feed pocket fens would allow us to determine whether the records of effective moisture from pocket fens reflect total precipitation or if there is a seasonal component to the records. Comparison of records of spring discharge and precipitation records would also allow for determination of the amount of lag time between precipitation and discharge. In order to take full advantage of the high resolution records of paleoenvironment provided by pocket fens, more AMS and Lead-210 dates are needed to provide the close chronological control to Arkansas and Platte records in order to determine whether depopulation and dispersal are linked to the timing of paleoclimate events between the Arkansas and the Platte basins, and to attempt to derive objective climate data from the records, as well as better understand the nature of response of pocket fens to changes in temperature and precipitation.

Methods for the Analysis of Pocket Fen Sediments

The characteristics of sediments reflect the conditions under which they were deposited. Increasing organic content in lake sediments has been demonstrated to reflect increases in temperature (Yang 1988), with decreases in organic carbon representing decrease in temperature and lake production or greater inorganic sediment influx (Doerner et al. 1998; Mayle et al. 1997). Recent analyses of peat from pocket fens suggest that the organic content (percent organic matter or % OM) may also respond in phase with temperature fluctuations. Organic matter content is determined using loss on ignition (LOI) techniques described by Dean (1974). Bulk density, organic content and humification are all determined from the same sample from a specific depth so the results of all analyses are directly comparable.

The relative rates and extent of peat decomposition (humification) in wetlands is primarily dependent on the depth of the water table. As plant detritus accumulates and becomes peat in the portion of the sediment column above the water table (acrotelm), it is exposed to oxygen which allows for much more rapid decomposition than after it passes into the continually saturated and anaerobic area below the water table (catotelm). Decomposition rates are up to 100 times greater in the acrotelm than in the catotelm (Malmer 1992a, 1992b). As precipitation decreases, spring flow decreases and the water table is depressed, more peat is exposed to oxygen and decomposition in the exposed portion of the sediment column is accelerated, which results in increased humic acid (Anderson 1998; Blackford and Chambers 1993). Fluctuations in the proportions of humic acid in sediment cores therefore serve as a proxy for changes in effective moisture. Values of relative humification were measured as the percent transmittance of light (%T) through a filtrate derived from each sample using the procedures outlined in Aaby (1976), Blackford and Chambers (1993) and Anderson (1998) and summarized in Taylor (2003). The effect of variation in organic content on the %T values was controlled by dividing %T by the grams of organic matter in each sample, and so humification values are reported as %T/OM.
Data Transformation and Display

In contrast to larger fens and bogs whose sections of organic sediment are relatively homogenous in their physical characteristics, pocket fens represent smaller, more dynamic systems whose hydrological and sedimentological characteristics vary more widely through time. Because of this, peat layers in pocket fens are often interbedded with mineral or lacustrine sediments, and this has required the development of new methods of data transformation and display to compensate for the heterogeneity of these sediments. Sediments in divergent segments of cores were characterized as peat, mucky sediments or lake sediments according to the criteria provided in the field identification of hydric soils (Hurt and Vasilas 2006), and then means and standard deviations for %OM and %T/OM were calculated for these different sections of core. Charts developed for these sediment records (Figures 5 and 6), display variations in the proxies above and below the mean (lighter colors), and periods where the data exceed more than one standard deviation above or below the mean (darker colors), the latter suggesting significant deviations of climate.

Most of these episodes of more extreme conditions reflected in the environmental proxies correlate to previously recognized paleoclimate events such as the Little Ice Age, the Medieval Climate Anomaly, and apparent anthropogenic climate warming of the past 150 years (Benedict 1973, 1985; Bradley 2000; Broecker 2001; Cook et al. 2004; Cook et al. 1999; Laird et al. 1996; Mann and Jones 2003; Woodhouse et al. 2002; Woodhouse et al. 1998). Extended periods of significant high amplitude deviation from mean conditions, especially those characterized by drought, can effect culture change as adaptations change to compensate to changing environmental conditions (Figure 7).

Like periods of extended high amplitude deviation in climate, periods of high temporal variation in environment also can contribute to culture change; in fact, high variability in climate can have major impacts on socio-economic and demographic patterns (Larson et al. 1996; Shennan 2003). Stable climate provides greater predictability in the amount and distribution of critical resources on a seasonal and annual basis, which in turn contributes to demographic and technological stability. During episodes of
high variability, the number and distribution of certain critical economic plants and animals fluctuates in ways that may be difficult or impossible to predict, and result in cultural instability. Episodes of greater variability in climate can be identified in the records of proxy climatic variables derived from pocket fen cores. Variability in the proxies is reflected in the standard deviation for these values. Graphing the nine-point running standard deviation for % OM and % T/OM for each core identified episodes of high climate variability. A section of each core where the running standard deviation was above the median standard deviation value was considered to represent an episode of high environmental variability. These episodes were aggregated for all of the available core records and if an episode occurred in more than 50% of the available records then the validity of the episode was considered to be high (Figures 8 and 9). These episodes were then compared to the proxy population records and cultural historical periods to examine the relationship between long-term trends in environment and episodes of high temporal variability in environment with population and culture change (Figures 10 and 11).

Figure 8. Episodes of high temporal variability in paleoclimate, expressed as above median values of running standard deviations for temperature proxy data (%OM). Episodes of above median values of running standard deviation in %OM indicate episodes of high temporal variability in temperature. Red diamonds indicate location of AMS dates.
Figure 9. Episodes of high temporal variability in paleoclimate expressed as above median values of running standard deviations of in effective moisture proxy data (%T/OM). Episodes of above median values of running standard deviation in %T/OM indicate episodes of high temporal variability in effective moisture. Red diamonds indicate location of AMS dates.
Figure 10. Episodes of high variability (above median running standard deviation) aggregated from all available records of temperature (%OM) compared to the population curves for the plains sub-regions of the Platte and Arkansas basins. Episodes of high variability in environmental conditions correspond to periods of population flux and culture change.
Figure 11. Episodes of high variability (above median running standard deviation) aggregated from all available records of effective moisture (%T/OM) compared to the population curves for the plains sub-regions of the Platte and Arkansas basins. The resolution of the episodes of high variability in effective moisture are not as great as those defined by the temperature proxy in Figure 10 because there are only three records of effective moisture, whereas there are five records of temperature.

Summary and Conclusions
This research greatly expands the environmental and geographic range of potential paleoclimate records from peatland archives, a source of paleoenvironmental research that has gained broad acceptance in Europe over the past two decades but only recently has begun to see application in North America. The research to date has demonstrated that sediment records from fens (minerotrophic, or ground water fed peatlands) contain records comparable to those from high-resolution and sensitive records of paleoenvironment from ombrotrophic bogs (precipitation fed peatlands) and the only source heretofore investigated. Even more important, this research also demonstrates that small peatlands in the semi-arid mid-latitudes outside the high elevation, high latitude and tropical environments where the vast majority of peatlands are found (Barber and Charman 2005) can also provide excellent records. New methods in data transformation and display developed during the preliminary research on pocket fens allows for the signals of regional and continental climate change to be separated from the signals of “background noise” specific to individual fens related to formation processes or variation in local conditions.
This research also expands the potential usefulness of the summed probability distribution of radiocarbon dates as a tool for examining the population dynamics of prehistoric hunter-gatherers. Variations of this technique have been used successfully in interpreting the population history of various geographic areas at various scales elsewhere, but the present study is believed to be the first to compare the population dynamics between different areas in an attempt to model the interaction of population, paleoenvironment and culture change. Although this technique should not be construed as a measure of absolute population numbers, it does seem to provide a useful proxy for documenting the general trends in population increase, decrease and stability over time. Because of the relatively light touch that the prehistoric inhabitants of eastern Colorado had on the landscape, determining the trends in population and comparing these between regions is difficult, at best. The technique offered here is a relatively high-resolution alternative to low-resolution estimates, and allows finer textured comparisons of population, environment and culture change between regions.

Future Research

The impacts of this research are multifaceted. Sediments from pocket fens are unique on the High Plains; they are superior to fluvial and eolian sediments in that they provide continuous records of paleoenvironment at a high level of resolution. The resolution of these records approaches those provided in tree-rings, and yet pocket fens are more common and often represent greater time depth than tree-ring records, which on the Great Plains are severely limited in their spatial distribution and temporal depth. This research not only provides a new source of information to workers with interests in the nature of climate change on the Great Plains, but because the techniques developed during the course of this research are applicable in general to any region of the world where perched water tables feed small peatlands, dissemination of this research will provide another option for the investigation of paleoclimate within the mid-latitudes both north and south of the equator. Analysis of data from these sources could provide a detailed context within which the specific responses of the semi-arid and arid areas of the mid-latitudes to current anthropogenic global climate change can be examined. In addition, the geochemical proxies derived from these small wetlands are derived using relatively simple and robust methods that are also pedagogically robust; they are easily taught to undergraduate students who can use them to conduct legitimate research. The proposed research also provides the context within which other proxies such as pollen, plant and animal macrofossils, diatoms, testate amoebae, ostracods, and various techniques based on isotope chemistry (hydrogen, oxygen and carbon) can be investigated. Due to over-drafting of aquifers for agricultural use and the historical destruction of wetlands as a result of the construction of ponds and reservoirs for agricultural use, pocket fens are a vanishing resource and efforts to collect data from those that still exist are of vital importance.
References Cited

Aaby, Bent.
1976 Cyclic climatic variations in climate over the past 5,500 yr reflected in raised bogs. 

Anderson, D.E.
1998 A reconstruction of Holocene climate changes from peat bogs in north-west Scotland. 

Barber, Keith, and Dan Charman
2005 Holocene Paleoclimate Records from Peatlands. In Global Change in the Holocene, 

Benedict, James B.
1999 Effects of Changing Climate on Game-animal and Human Use of the Colorado High 

Binford, L. R.
1968 Post-Pleistocene Adaptations, in New Perspectives in Archaeology, Sally R. Binford and 

1983 In Pursuit of the Past: Decoding the Archaeological Record. Thames and Hudson, New 
York.

Blackford, J.J.
1990 Blanket mires and climatic change: a paleoecological study based on peat humification 
and macrofossil analysis. Unpublished PhD dissertation, Keene University, United 
Kingdom.

Blackford. J. J. and Chambers, F. M.
1993 Determining the degree of peat composition for peat-based paleoclimatic studies. 

1991 Blanket peat humification: evidence for a Dark Age (1400 B.P.) climatic deterioration in 

Boserup, E.

Bradley, Ray
Brenner, Mark, David A. Hodel, Jason H. Curtis, Michael F. Rosenmeier, Michael W. Binford, and Mark B. Abbott

Broecker, Wallace S.

Chambers, Frank M., and Dan J. Charman

Chatters, James C.

Cobb, Charles R. and Brian M. Butler

Cohen, M.


Dean, Walter Jr.

Dean, Walter E. and Eville Gorham

Doerner, James P.
Doerner, James P., Donald G. Sullivan, and Christy Briles

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Elias Scott A., and Laurence J. Toolin

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Forman, S.L., A.F.H. Goetz, and R.H. Yuhas

Gill, Richardson Benedict,
Gill, Susannah  

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Gilmore, Kevin P., and Donald G. Sullivan  


Gilmore, Kevin P., Marcia J. Tate, Mark L. Chenault, Bonnie J. Clark, Teresa McBride, and Margaret Wood  
Gorham, Eville, John W.G. Lund, Jon E. Sanger and Walter E. Dean, Jr.

Hassan Fekri

Hayden, Bryan


Hill, J. Bret, Jeffery J. Clark, William H. Doelle, and Patrick D. Lyons

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Lipe, William D. and Mark D. Varien  

Mackereth, F. J. H.  

Madole, Richard F.  

Maher, L. J.  

Malmer, Nils, and Bo Wallen  

Mann, Michael E. and Phillip D. Jones  

Mayle, F. E., Lowe, J. J., and Sheldrick, C.  

McFaul, Michael, Karen Lynn Traugh and Grant D. Smith  

Minnis, P. E.  

Pennak, R. W.  
Reed, Alan D., and Michael D. Metcalf

Richerson, Peter J., Robert Boyd and Robert L. Bettinger

Roos-Barraclough, Fiona, W.O. van der Knaap, J.F.N. van Leeuwen, and W. Shotyk

Short, Susan K.

South, A. B. and R. E. Kenward

1998  INTCAL98 Radiocarbon Age Calibration, 24000-0 cal BP  *Radiocarbon* 40(3) 1041-1083

Stuiver M. and P.J. Reimer
1993  Extended 14C data base and revised CALIB 3.0 14C Age calibration program  *Radiocarbon* 35(1) 215-230

Sullivan, Donald G.


Sullivan, Donald G. and Kevin P. Gilmore
2006a  Integrating Humification Analysis in Multi-Proxy Paleoenvironment Investigations in Minerotrophic Peatlands in Colorado, USA.  Poster presented at the fall meeting of the American Geophysical Union, San Francisco.


2005  Late Holocene climate changes and their influence on effective moisture in Colorado: evidence from peat humification analysis.  Program and Abstracts, Annual Meeting Great


Sullivan, Donald G., Zachary P. Taylor, and Tenille J. Williams

Taylor, Zachary P.

Upham, Steadman


Weakly, Harry E.

Weakly, Ward F.

Weiss, Harvey, and Raymond S. Bradley

Williams, Tenille J.

Woodhouse, Connie, J.J. Lukas, and P.M. Brown
Woodhouse, Connie A. and Jonathon T. Overpeck

Yang, In Che

Zier, Christian J., and Stephen M. Kalasz