A LOW-FREQUENCY PALEOCLIMATIC RECONSTRUCTION FROM THE LA PLATA MOUNTAINS, COLORADO AND ITS IMPLICATIONS FOR AGRICULTURAL PRODUCTIVITY IN THE MESA VERDE REGION

By

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A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF ARTS IN ANTHROPOLOGY

WASHINGTON STATE UNIVERSITY
Department of Anthropology

DECEMBER 2006

To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of AARON M. WRIGHT find it satisfactory and recommend that it be accepted.

Chair

ACKNOWLEDGMENT

I thank my committee members for their patience and guidance throughout the various stages of research presented in this thesis. I am grateful to Dr. John Jones for teaching me the basics of pollen processing, pollen analysis and binocular microscopy. Likewise, without Dr. Jones's oversight, I would not have been able to positively identify many of the uncommon pollen types preserved in the Beef Pasture pollen assemblage. Many thanks are directed to Dr. Tim Kohler, who offered me the opportunity to undertake this intensive study and for assistance with statistical methods. Further, funding for this project was provided by a National Science Foundation grant (No. BCS-0119981) awarded to Dr. Kohler. Dr. Andrew Duff provided consistent intellectual support throughout my research, and I thank him for reminding me of the 'bigger picture' of prehistoric population dynamics in the Greater Southwest. Dr. Ken Petersen of the University of Utah developed many of the analytical methods and background information regarding subalpine vegetational response to climatic change in the La Plata Mountains, and I thank him for providing this essential foundation for the current study. I am indebted to Dr. George Burr from the University of Arizona's Accelerator Mass Spectrometry Laboratory, who offered me an opportunity to learn hands-on the basics of radiocarbon sample processing and interpretation. Through his generous efforts I was able to add 11 radiocarbon dates to the current study, which has greatly enhanced the chronological control and temporal resolution of the Beef Pasture pollen record. Lastly, I thank Kyla Rudnick for her assistance with drafting several of the figures presented in this thesis as well as her patience and understanding throughout the many long days of analysis and writing. Although these colleagues graciously assisted me throughout my research process and writing, I take full credit for any errors in logic, grammar and presentation.

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Abstract

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December 2006

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This thesis presents pertinent data on the low-frequency paleoclimatic regime of the Mesa Verde region in southwestern Colorado from B.C. 100 to the present era. Here, I define low-frequency climatic changes as climatic changes over periods greater than 20 years. I place interpretive emphasis on the period A.D. 600 – 1300, an era of continuous habitation by ancestral Puebloan farmers in the central Mesa Verde region. These data are intended for use in the Village Project's agricultural paleoproductivity model, which seeks to derive estimates of maize production in the central Mesa Verde region during the 700 years of continuous occupation. Knowledge of low-frequency climatic processes is critical to understanding subsistence practices because they not only establish a region's carrying capacity, but they are also assumed to represent the normative climatic conditions perceived by a population. A tentative comparison of regional paleodemography to low-frequency climate changes suggests that demographic processes are broadly correlated with low-frequency climatic conditions, likely due to associated fluctuations in agricultural productivity.

This study consists of an intensive analysis of 72 closely-spaced stratigraphic pollen samples from a subalpine fen in the La Plata Mountains, southwestern Colorado; 16 radiocarbon samples provide temporal control. The results offer data on the most closely sampled and radiometrically dated pollen core of lacustrine sediments from the past 2,100 years in North America. I use these data to reconstruct low-frequency changes in regional temperature, summer precipitation and winter precipitation, all of which are critical to agricultural production in Mesa Verde region. This reconstruction uses five indicator taxa whose existence around the fen is dictated largely by these climatic conditions: Engelmann spruce, ponderosa pine, pinyon pine, sedge and an inclusive category of plants belonging to the Chenopodaceae family and *Amaranthus* genus. I argue and demonstrate that changes in the proliferation of these taxa around the fen occurred in response to climatic fluctuations that dictate their distribution. Therefore, I interpret changes in the proliferation of these taxa as changes in associated climate variables, and I extrapolate these climate changes into a regional context that includes the Village Project's study area in the central Mesa Verde region.

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CHAPTER ONE

INTRODUCTION

Paleoenvironmental and paleoclimatic reconstructions are essential contextual components (Butzer 1982) for understanding the history and complexity of cultural configurations and changes amidst the dynamics of physical and social environments. As an aspect of cultural change, demographic processes in the southwestern United States are often analyzed in relation to environmental changes due to the relationships between subsistence potential and the climatic parameters that strongly influence the productivity of particular cultigens. Since various culture groups resided in the Greater Southwest in the pre-Hispanic era, differences in their cultural compositions and social knowledge highlight the potential for different sociocultural responses to similar environmental or climatic changes. One thing these people did share, however, was the ability to use mobility as a survival strategy when facing subsistence related stresses (e.g., Cordell and Plog 1979; Hard and Merrill 1992; Reid et al. 1996; Schlanger 1988; Varien 1999; Zedeño 1994).

This research focuses primarily on defining low-frequency fluctuations (> 20 years) (see Dean et al. 1985) in the climatic regime of the Mesa Verde region of the northern San Juan region (Figures 1 and 2) from A.D. 600 - 1300, a time when regional inhabitants became sedentary and increasingly reliant on a corn-based subsistence strategy. While higher frequency paleoclimatic changes in this region are well known and have been the concern of much research, low-frequency processes are poorly understood and have not been studied to an extent compatible with the well dated demographic and cultural changes that occurred in the northern Southwest. Both high- and low-frequency climatic changes play critical roles in subsistence-

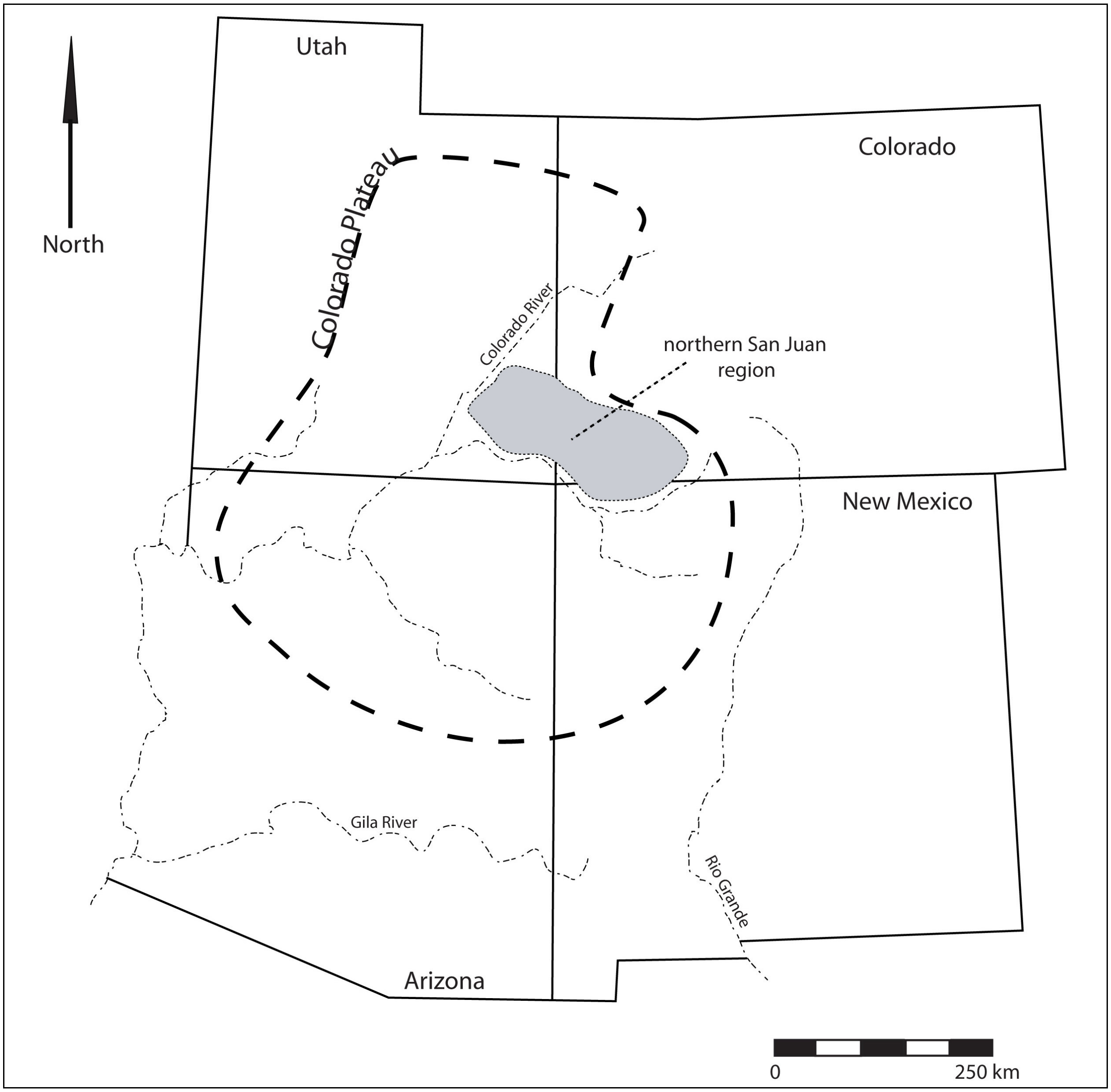

Figure 1. Northern San Juan region in a geographical context of the Greater Southwest.

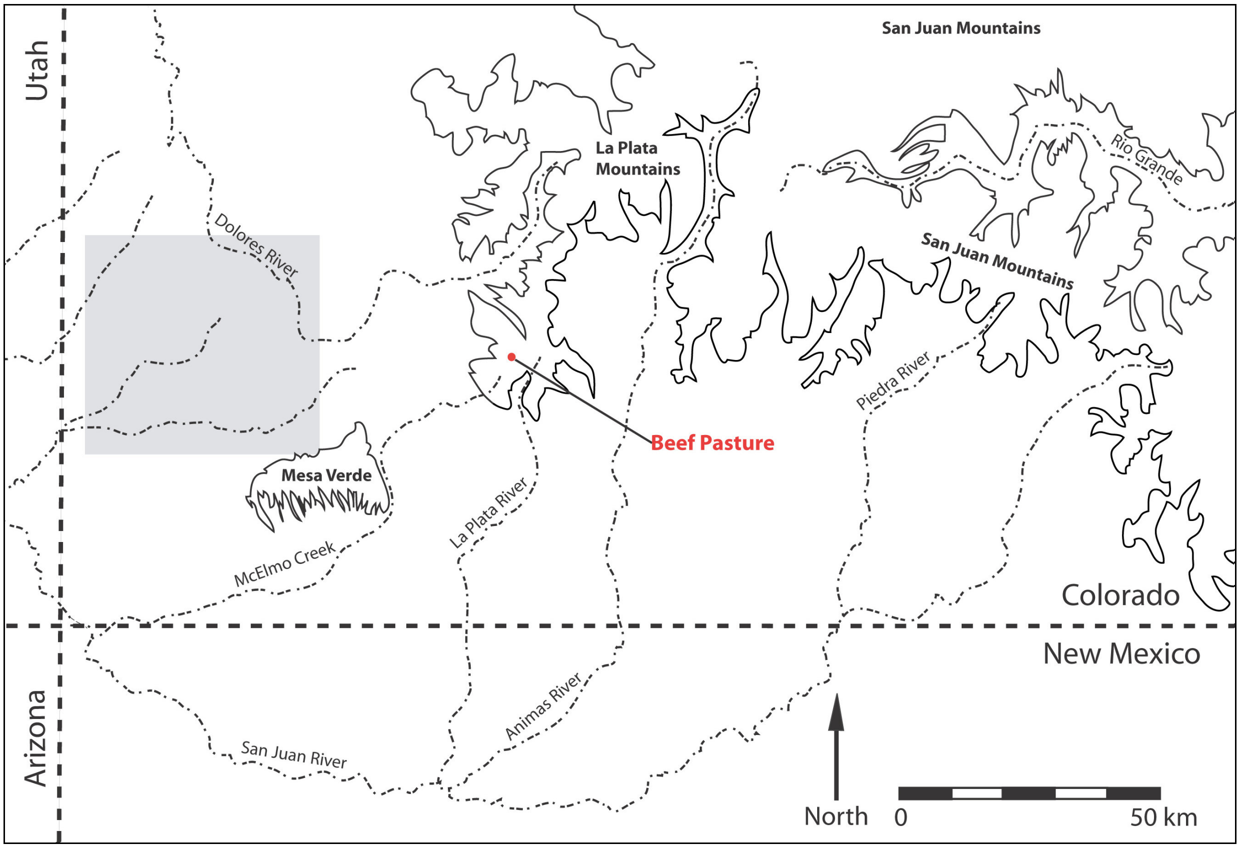

Figure 2. Diagram of southwestern Colorado showing Beef Pasture in relation to geographical features discussed in text. The shaded area corresponds to the Village Project's study area.

related activities, and information on both scales of climatic change is necessary for studying human-environment relationships. Dean et al. (1985:538-539) have described the importance of both low- and high-frequency environmental changes on human demography:

> Low-frequency environmental processes usually are not apparent to humans; conditions established by these processes probably are perceived as 'stability.' High-frequency variability is apparent to human populations, and most behavioral buffering mechanisms are adaptations to expectable high-frequency fluctuations. The importance of both high and low-frequency environmental variability varies in relation to a number of factors, the most important of which is how close the

> adaptive system is to carrying capacity. High-frequency fluctuations are usually of little consequence when the population is well below carrying capacity; however, as the population approaches the long term carrying capacity established by low-frequency processes, high-frequency variability becomes more critical to survival. When low-frequency environmental changes reduce carrying capacity below the level required for the maintenance of the population, the population can no longer be sustained by the extant subsistence system.

As they suggest, the effects of high-frequency environmental variability on demography and cultural change vary in relation to how close the environment is to reaching the human carrying capacity of the region. Carrying capacity is dictated by population pressure, the subsistence system of the population, and the environmental limits of the region. These environmental limits are established by low-frequency processes, and high-frequency processes become more critical the closer the environment approaches carrying capacity. In sum, understanding the effects of high-frequency environmental change on populations and their subsistence systems requires knowledge of the carrying capacity, which is dictated largely by population size and the environmental parameters that are set by low-frequency processes.

In this chapter I provide a brief review of the relevance of paleoclimatic data to understanding the paleodemography of the Mesa Verde region and make a case for the utility of pollen-based paleoclimate reconstructions in archaeological research. An overview of the known climatic processes of the Greater Southwest orients the reader to several of the forces causing climate change in the region. A subsequent discussion on the required climatic conditions for maize agriculture demonstrates the need for paleoclimatic data for understanding agricultural paleoproductivity in the Mesa Verde region. In the final section I review the existing literature on pollen-based paleoclimate reconstructions in the northern Southwest and show how this thesis contributes to our understanding of paleoclimatic changes in relation to archaeologically relevant periods.

Agricultural Paleoproductivity in the Mesa Verde Region

The Puebloan culture (Kidder 1927) was manifested in the Mesa Verde region as a complex array of sedentary communities, reliant mainly on dry-farming agriculture and centered, in most periods, on the region's most productive agricultural lands (Varien 1999; Varien et al. 2000). Ultimately, Puebloan peoples left these communities in favor of other places peripheral to the San Juan region, and this translocation has traditionally been viewed as an adaptive response to a prolonged drought during the latter half of the thirteenth century (e.g., Douglass 1929; Hewett 1908; Kidder 1924). More recent research by Van West (1994, 1996), Varien (1999) and Varien et al. (2000), however, suggests that regional agricultural productivity would not have been limited by precipitation to such an extent that all established communities could no longer be supported by means of agricultural subsistence.

Van West's agricultural paleoproductivity research, however, has not entirely closed this debate. A more recent paleoproductivity model for Van West's research area in southwestern Colorado, developed by the "Village Ecodynamics" project, reconstructs maize production estimates that are considerably lower than Van West's, though this reconstruction, discussed in more detail below, would not preclude continuing occupation of this area by reduced populations in the 1300s (Kohler et al. 2007). Others agree that while successful maize cultivation could have occurred in several areas regardless of prolonged moisture deficiencies, thus enabling continual occupation of such areas throughout the megadrought of the mid-twelfth century and the Great Drought near the end of the thirteenth century, the effects of droughts across the region would have contributed to a breakdown in social structure, thus establishing possible incentives to leave the area and gain residence in more socially stable communities elsewhere (Benson et al. 2006; see also Axtell et al. 2002; Dean et al. 2000; Larson et al. 1996).

Further complicating the picture is the possibility that the local onset of the cold period known as the Little Ice Age (A.D. 1250 – 1850) may have also reduced or eliminated maize production in the northern Southwest during certain periods of extreme cooling (Adams and Petersen 1999; Petersen 1988, 1994; see also Grove 1988; Matthews and Briffa 2005; Porter 1986; Van West and Dean 2000). So the status of climate change as the chief instigator for the widespread depopulations in the northern Southwest is once again hotly debated. My current research, therefore, specifically aims to pinpoint periods of increased and reduced duration in annual growing seasons that may have affected regional agricultural productivity in conjunction with changing precipitation patterns.

I now turn to a review of the history of environment-based archaeological research in the Mesa Verde region. I discuss further how the Village Ecodynamics project expands our knowledge of the paleoenvironmental conditions in the Mesa Verde region and how these new data augment previous agricultural paleoproductivity models.

Project Background

Detailed paleoenvironmental reconstructions for the Mesa Verde region, overseen by Ken Petersen, were a primary research component of the Dolores Archaeological Program (DAP), which engaged in archaeological research along the Dolores River from 1978 to 1985. The DAP was the facet of the Dolores Project that dealt with the mitigation of cultural resources along the Dolores River in Montezuma County, Colorado that were to be destroyed by the construction of McPhee Dam and associated recreational facilities. The Dolores Project was directed by the

U.S. Bureau of Reclamation; the University of Colorado was the primary contractor (David A. Breternitz, Senior Principal Investigator) for the DAP, with Washington State University as a major subcontractor.

Paleoenvironmental data were extremely relevant to the DAP's research design because the DAP area sits at the extreme local northeastern boundary of the Puebloan distribution and it seemed quite plausible that this limit was climatically controlled (Petersen et al. 1986). Paleoenvironmental data were used to examine many of the questions posed in DAP's original research design (Kane et al. 1983), such as the nature of aggregation, the source of population growth, the causes for the nearly complete depopulation of the project area around A.D. 900, and to test some of the interrelationships between environment and population posited in the DAP's cultural modeling efforts (Breternitz et al. 1986; Lipe 1984). Some of the results from the DAP are presented in Blinman et al. (1988), Breternitz (1983, 1984), Breternitz et al. (1986), Gross and Kane (1989), Kane and Gross (1986), Kane and Robinson (1986, 1988), Kane et al. (1986), Kohler et al. (1986), Lipe et al. (1988), Madden and Weakly (1980), Petersen and Orcutt (1987) and Petersen et al. (1985).

I initiated the current project to obtain pertinent paleoenvironmental data for use in "The Village Ecodynamics" project, a computerized simulation designed to model the settlement ecodynamics in the central Mesa Verde region (Figure 2) during ancestral Puebloan occupation from A.D. 600 - 1300 (Johnson et al. 2005; Kohler and Carr 1997; Kohler et al. 2000, 2007; Varien et al. 2007). The Village Project continues, and elaborates on, earlier modeling efforts of the DAP (especially Kohler et al. 1986, but see also Lipe 1984). The ultimate aims of the Village Project are to reconstruct the environmental conditions in southwestern Colorado from A.D. 600 to 1300 by using multiple proxy records, to explore the 'ecological niche' (see Odling-

Smee et al. 2003) constructed by regional agriculturalists, and to better understand the co-evolution of regional societal structures and environments over the 700 years of continuous occupation (Kohler et al. 2007).

An integral component of this simulation is the development of a reliable resource-availability model for maize (*Zea mays*) production that integrates aspects of soil hydrology, seasonal precipitation patterns, and annual temperature measures, all of which influence the productivity potential of dry-farming practices. Although variable degrees of reliance on maize agriculture should be expected across communities and households in this region, macrobotanical and stable carbon isotope analyses support the commonly held notion that maize was the most important subsistence resource on the Colorado Plateau by at least A.D. 600, with some possible exceptions in marginal areas (see Kantner 2004:60-67). For example, Decker and Tieszen (1989) estimated that maize provided 70 to 80 percent of the caloric intake of Mesa Verdean populations during the thirteenth century.

The Village Project's new resource availability model, like that of Van West (1994), uses the Palmer Drought Severity Index (PDSI) for calculating maize productivity on particular soil classes. Palmer (1965) developed the PDSI as a relative measure of soil moisture for different soil classes under known precipitation patterns; Burns (1983) was the first to realize the utility of this index for archaeological research. In Van West's (1994) model, records of maize and bean production in Montezuma County, Colorado from 1931 to 1960 are compared to contemporaneous PDSI values of different soil classes in this region to develop predictions of maize productivity under various climatic conditions in prehistory. The extrapolation into prehistory is possible because PDSI measures can be retrodicted through regional tree-ring records. Van West's model, however, did not explicitly address the role of temperature variability in agricultural productivity.

To account for high-frequency changes in regional temperatures, the Village Project incorporates proxy data for cold and short summers from regional tree-ring data. Two high-elevation bristlecone pine (*Pinus aristata*) sequences were selected for this project: one from Almagre Mountain, situated approximately 350 km east-northeast of the project area, and another from the San Francisco Peaks (Salzer 2000a), located approximately 335 km southwest of the project area. Temperature measures were calculated by extracting the first principal component of both sequences; annual scores so derived proved to be highly correlated with various local measures of temperature in and near the Village Project study area.

In the following section I argue that pollen proxies can help overcome several limitations of low-frequency paleoclimatic reconstructions derived from tree rings. I outline further how pollen-based paleoclimatic reconstructions augment those derived from tree rings, primarily the distinction between seasonal precipitation patterns.

Limitations of Paleoclimatic Reconstructions Derived from Tree Rings

Prehistoric fluctuations in climatic regimes have been successfully identified through various biotic and abiotic proxies, including but not limited to tree-ring sequences, pollen records, packrat middens, insect fossils, chemical isotope analyses and geomorphology. While tree-ring climatic reconstructions have received most of the attention, due to the high temporal resolution that they provide, there are several limitations to low-frequency climate reconstructions from such data (Cook et al. 1995, 1996; Dean 1988, 1996b; Fritts 1991). First, tree-rings express the climatic conditions of a tree's immediate environment, which may differ significantly from surrounding areas and not reflect regional conditions. Second, tree-ring chronologies are composites derived from multiple trees, often from different localities, and the life spans of such trees are less than the duration of many of the low-frequency climatic processes that we want to identify. Further, many of the earlier chronologies are derived from relatively short tree-ring series from archaeological contexts, many of which are relics of modified architectural materials that do not have a known geographical origin.

In conjunction with these limitations, a potential problem arises when attempting to extrapolate data on low-frequency changes in temperature and precipitation from tree-ring sequences. While tree rings express high-frequency, year-to-year fluctuations very accurately, long-term trends on the order of several decades or more (low-frequency) are poorly reflected because of the tree's ability to adapt to such conditions. Thus, the widths of tree rings reflect not only high-frequency climate change but also the organism's adjustment to climatic perturbations, obfuscating and minimizing the magnitude and duration of the climatic change. Moreover, tree rings may only demonstrate how individual trees, tree species or tree communities responded to climate change in the past, whereas realistic data on perturbations in the structure of vegetational communities and their distributions across the landscape resultant from climatic change must come from the actual remains of such organisms. While it is impossible to decode such phenomena solely from a single proxy, pollen sequences from aquatic locations provide continuous records of change in adjacent vegetational communities. In alpine settings such records have the potential to express the succession of species, plant communities and forest structures that result mainly from low-frequency climatic changes.

To overcome the limitations to low-frequency climatic reconstructions from tree-ring chronologies, I use here an alpine pollen record from Beef Pasture in the La Plata Mountains of southwestern Colorado (Figure 2) to identify changes through time in the elevation of the boundary between the subalpine and montane forest zones that reflect prolonged changes in the amount of winter snowpack, which results from fluctuations in the amount of winter precipitation and/or annual temperature. Since most of the tree-ring-based precipitation reconstructions for the Southwest are calibrated with either annual or winter/early spring precipitation more than with summer precipitation (Fritts 1976:139-140), they limit our ability to differentiate seasonal precipitation patterns. As an effort to distinguish between seasonal precipitation patterns, I use pinyon pine (*Pinus edulis*) pollen influx as a relative measure of low-frequency changes in summer precipitation, and I further use measures of other taxa (i.e., *Carex* sp., Chenopodiaceae, and *Amaranthus* sp.) to identify similar changes in winter precipitation.

Alpine pollen records provide an opportunity to elucidate low-frequency climate changes that are poorly expressed in the tree-ring record. These data provide an opportunity to extrapolate relative durations of increased and reduced annual temperatures that would have altered the length of the growing season at lower elevations, and they provide further an opportunity to differentiate between the winter and summer precipitation regimes. I now turn to a discussion on the likely causes for the paleoclimatic fluctuations observed in pollen and tree-ring proxies. A thorough comparison of these to the fluctuations identified in my paleoclimatic reconstruction, however, is beyond the scope of this thesis.

Overview of Climate Patterns in the Northern Southwest

The known climatic processes of the northern Southwest, at both high- and low-frequency scales, are the likely mechanisms of climatic change that occurred in the past. The relationships between high- and low-frequency climate changes, however, are still poorly understood due to a lack of low-frequency studies, poor temporal resolution in such studies and the infancy of meteorological instrumentation, research, modeling and theory. Simply put, the modern era of scientific climatology has not existed long enough to place well-known high-frequency changes in low-frequency contexts, and the extrapolation of what is known about modern climatological patterns and relationships into the pre-industrial era is problematic because we still do not fully understand the effects of greenhouse gases and deforestation on established climatic regimes (Mann et al. 1999; Trenberth and Hoar 1996, 1997; see also Cook et al. 1995).

Regardless of the potential problems that arise from extrapolating modern climatological relationships and patterns into prehistory, we do know, and continue to learn about modern climatological patterns that likely existed in prehistory. Petersen (1988:14-20) discusses the climatic patterns and relationships for the Greater Southwest, and these will be summarized and updated here. Precipitation occurs in a bimodal pattern in the Greater Southwest, in which snow and rain are deposited during the winter and early spring months and rain falls during the summer monsoons. This bimodal precipitation pattern is discussed at length in Sellers (1960) and Sellers and Hill (1974:4-19). Based on tree-ring records, Dean (1996a, 1996b) suggests that this pattern has been the normative climatic regime across the Greater Southwest from A.D. 966 to 1988. Ahlstrom et al. (1995), however, note that the Mesa Verde region witnessed a period of unpredictable and unstable precipitation between A.D. 1250 and 1450.

Dean (1988:123) suggests that annual variation in rain is driven largely by fluctuations in winter/early spring precipitation because these differ more from year to year than does the more predictable summer rainfall. Summer monsoons in July and August are caused by the Bermuda high-pressure system (Allen 2004:22), which extends from the Atlantic Ocean to the central United States and carries moist air from the Gulf of Mexico into the Greater Southwest. Along with the Bermuda high-pressure system, moisture from the south and southwest is brought into the Four Corners area during August and September via surges of moist air that originate from tropical cyclones off the west coast of Mexico and the Gulf of California.

Precipitation from November to March is dictated largely by the polar jet stream, which brings moist air from the west into the area and deposits precipitation. The jet stream is a current of low atmospheric pressure that usually enters the North American continent via the Pacific Northwest and tends to traverse southward along the eastern side of the Rocky Mountains, thus avoiding the Greater Southwest and resulting in relatively dry and windy winters. This jet stream usually follows the northern edge of a high-pressure system off the West Coast, however, this high-pressure system is occasionally located further to the west. When it is, the jet stream enters the North American continent further south and then traverses eastward across the Greater Southwest and deposits above-average winter precipitation.

The relatively new concept of the El Niño/La Niña Southern Oscillation also affects the high-frequency precipitation patterns of the Greater Southwest. During El Niño years anomalous low-pressure systems coupled with above-average sea-surface temperatures (SSTs) in the Pacific Ocean result in increased winter and spring precipitation in the Greater Southwest (Andrade and Sellers 1988; Ropelewski and Halpert 1986). Droughts associated with La Niña cycles often occur during the interim of these El Niño events (Molles and Dahm 1990). Quinn and Neal (1992) suggest that significant El Niño episodes occurred at an average of every 4 years (ranging from 2 – 6 years) between A.D. 1524 and 1987. Quinn and Neal’s research also demonstrates a period of relatively infrequent wet El Niño conditions between A.D. 1000 and 1500. A record of southwestern floods developed by Ely et al. (1993) evidences a period of low flood-frequency from A.D. 1200 to 1400, presumably due to drier conditions as a result of the suppressed frequencies of El Niño years suggested by Quinn and Neal (1992), but the periods from A.D.

1000 to 1200 and A.D. 1400 to the present witnessed higher flood frequencies likely due to southern shifts in the polar jet stream.

The Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal Oscillation (AMO) also influence the climatic regime of the Greater Southwest. The PDO, an index of Pacific Ocean SSTs, is similar to the El Niño phenomenon in spatial extent (Mantua et al. 1997), however, the PDO ranges from 50 to 70 years in duration (MacDonald and Case 2005). The Southwest tends to have higher-than-average precipitation during warmer-than-normal Pacific SSTs (positive PDO) and vice versa (Benson et al. 2006), and winter precipitation in New Mexico is positively correlated with the PDO (Brown and Comrie 2002; Ni et al. 2002). The AMO is an average measure of Atlantic Ocean SSTs between 0 and 70º N (Kerr 2000), and it has expressed a cyclicity of 65 to 80 years since A.D. 1856 (Benson et al. 2006). Although research on the PDO, the AMO and their interrelationships is in its infancy, atmospheric modeling efforts suggest that droughts in the western United States are associated with positive AMO and negative PDO phases (Fry et al. 2003; Schubert et al. 2004).

In the next section I discuss the climatic requirements for maize agricultural and demonstrate how data on precipitation and temperature are critical for estimating agricultural paleoproductivity in the Mesa Verde region.

Corn and Climate in the Mesa Verde Region

Considering that maize was the most important subsistence resource for regional populations between A.D. 600 and 1300, the climatic parameters for the successful production of this crop in the Mesa Verde region need to be addressed. Regarding dry-land agricultural practices, Adams and Petersen (1999:23) highlight the importance of a biseasonal precipitation pattern, where soil moisture from winter precipitation is necessary for plant germination and summer precipitation is critical for maturation. Hack (1942:23) originally suggested that maize agriculture on the Colorado Plateau required at least 12 inches of annual rainfall; Petersen (1988:11) augmented that to a minimum of 14 inches for the Mesa Verde region. Milo (1991), however, argues that annual precipitation is a poor measure when considering growing-season requirements, and precipitation measures should therefore be distinguished for each mode in the biseasonal pattern. In this study I differentiate between low-frequency fluctuations in winter and summer precipitation based on appropriate biotic indicators.

Petersen (1988) realized that variability in maize productivity in the Mesa Verde area, probably more so than in lower, more southern areas, is dictated by temperature as well as by precipitation. Some earlier research (e.g., Berlin et al. 1977:59; Martin and Byers 1965:135; Smiley 1961:703; Woodbury 1961:708-709) had also hypothesized that reduced temperatures may have influenced the Mesa Verde regional depopulation during the thirteenth century, and more recent investigations (e.g., Salzer 2000b) have given increasing attention to the role of temperature in agricultural productivity during this turbulent period.

In general, modern maize agriculture rarely takes place in areas with an average growing season temperature less than 19º C (66.2º F) (Shaw 1988), and normal plant growth occurs when temperatures range between 10 and 40º C (50 and 104º F) (Tivy 1990). A minimum of 110 to 130 frost-free days is generally required for most varieties of Corn Belt dent hybrids of maize to mature (Adams 1979:291; Adams and Petersen 1999:26; Hack 1942:20, 23; Salzer 2000b:297), however, some southwestern maize cultivars are adapted to a shorter season of 60 to 90 frost-free days (Meunchrath and Salvador 1995). Frost-free days are generally calculated as the sum of days during a growing season when temperatures do not fall below 0º C (32º F). However, maize can tolerate temperatures as low as -3º C (26.6º F) during both germination and maturation (Chang 1968:101), therefore, total frost-free days as a measure of growing season duration may be misleading for understanding maize productivity (Milo 1991).

Regardless of the intricacies of maize production and disagreements on the standard for calculating grow season duration, all parties agree that cold periods are detrimental to maize productivity. Early-season cold spells can delay germination and shoot development, while prolonged episodes of cool temperatures inhibit overall plant development, lengthening the period for germination and growth. Unexpected frosts can kill plants by creating ice crystals that dehydrate or damage the cellular structure of the plant. Ritchie et al. (1992) suggest, however, that late frosts are more problematic than earlier ones because during the first three weeks after germination plant production is focused underground and is therefore largely protected from the formation of ice crystals. In fact, maize is most sensitive to cold periods while it is flowering, which occurs near the middle of the growing season when freezing temperatures are least likely to occur (Adams and Petersen 1999:26).

While agricultural productivity in the Mesa Verde region is thus susceptible to relatively slight changes in precipitation and temperature, our ability to develop intraseason measures of precipitation or temperature in the past from palynological data is extremely limited. Fall (1997b) has used terrestrial lapse rates to retrodict quantifiable climatic parameters in central Colorado. Terrestrial lapse rates allow for estimates of a temperature at elevation ‘X’ when such conditions are known at elevations both lower and higher than ‘X’ (Axelrod 1965). This method is often simplified for large geographic areas with the following equation: $(T^{sl} – T^{u}) * (1000\ m/5.5^{o}\ C)$, where T^{sl} is the mean annual temperature at sea level, T^{u} is the mean annual upland temperature, and 1000 m/5.5º C (or 182 m/-1º C) is the constant rate of change in temperature with change in elevation (Meyers 1992:71). Barry and Bradley (1976) devised a summer terrestrial lapse rate of 100 m/-0.82º C for the Durango area and an annual terrestrial lapse rate of 100 m/-.59º C for the San Juan National Forest.

The use of terrestrial lapse rates as a method for estimating paleotemperatures, however, has been criticized by some paleoclimatologists for disregarding many of the contextual intricacies relevant to reconstructing a locality's paleoclimate, such as the region's geological structure, topography and microenvironments (e.g., Meyers 1992). Furthermore, the lower boundary of the subalpine forest at Beef Pasture is gradational and a blending of two forest types occurs. This boundary is unlike the discrete upper boundary of the subalpine forest for which terrestrial lapse rates are often calculated when using pollen data (e.g., Fall 1997b). In the present case, though, reconstructed shifts in the elevational boundaries of vegetative zones are useful for reconstructing climate parameters without attempting to derive estimates of paleotemperatures. I will use the palynological data from Beef Pasture to identify ordinal (wetter/drier and warmer/cooler) rather than interval measures through time. Coupling these palynological data and other studies of low-frequency climate change with high-frequency records that provide interval-level estimates of temperature and precipitation (e.g., Dean and Van West 2002; Salzer and Kipfmueller 2005) can provide more robust measures of changing paleoclimates (Swetnam et al. 1999). While such an effort is a critical element of the Village Project, it is beyond the realm of the present study.

I now turn to a review of existing pollen-based low-frequency paleoclimatic reconstructions from the northern San Juan region to demonstrate how the current project adds to the existing database.

Previous Paleoclimatic Research

Paleoenvironmental reconstructions in the Four Corners area have relied on a variety of proxies and have been conducted in a range of locations, however, many have relied on discontinuous sequences as a result of climatic change, geological processes or anthropogenic disturbance. Since Bryant and Holloway (1983) and Hall (1985a, 1985b) provide a comprehensive review of many pollen studies undertaken in the Greater Southwest, I will not present these here. Likewise, a complete review of past efforts at paleoenvironmental reconstruction from other proxy data in the Southwest is beyond my scope here, though I will briefly review and synthesize palynological research at Mesa Verde and surrounding areas to set the stage for the current study.

Palynological research in service of understanding past climates in the Mesa Verde region has been largely limited to peat-bog sequences from the La Plata Mountains. As part of the Eastern New Mexico State University's Salmon Ruins Archaeological Project at Bloomfield, New Mexico, Petersen and Mehringer (1976) analyzed a sediment core from Twin Lakes, La Plata Mountains, Colorado to investigate the past history of summer temperature fluctuation in the Four Corners area. Petersen (1975) continued his paleoenvironmental investigations by analyzing pollen cores from Beef Pasture, also in the La Plata Mountains. These early investigations laid the ground work for the extensive research conducted later by the Environmental Archaeology Program of the DAP. As part of the DAP, Petersen (1988) analyzed additional samples from the Twin Lakes and Beef Pasture pollen cores, and he also incorporated data from a pollen core extracted from Sagehen Marsh located within the DAP project area.

As a preliminary study for the current project, Wright and Petersen (2005) conducted additional palynological research at Beef Pasture. In an effort to reconstruct the environment around the Navajo Reservoir and Chuska Valley areas of northwest New Mexico (south of our project area), Schoenwetter (1966, 1967, 1970, 1987; Schoenwetter and Eddy 1964) compared modern pollen ratios and pollen spectra of local environments to those from numerous archaeological and alluvial deposits. As part of the archaeological research at Black Mesa, Arizona (southwest of our project area) in the late 1970s, Hevly (1988) conducted palynological investigations in an attempt to identify low-frequency environmental changes that were not clearly expressed in tree-ring data.

Additional palynological studies relevant to western Colorado were conducted in the San Juan Mountains (Andrews et al. 1975; Maher 1961, 1963) and elsewhere within the Rocky Mountains of central Colorado (Fall 1985, 1988, 1997a, 1997b; Feiler et al. 1997; Maher 1972a; Markgraf and Scott 1981; Pennack 1963; Short 1985; Vierling 1998). Although these areas are not generally considered to be part of the Greater Southwest, their vegetational assemblages are quite similar to those of the La Plata Mountains. Likewise, the Mesa Verde region is located between these areas and the northern Arizona and northern New Mexico localities where much stratigraphic palynological research has been conducted. Therefore, environmental reconstructions from the La Plata Mountains should eventually be compared to similar studies from both of these areas to put my results in a larger geographical context. Since the aim of my research is to isolate climatic change particular to the Mesa Verde region, I make no effort here to correlate and compare my results to those of other regions. Furthermore, broad regional correlations will be imperfect due to vagaries in localized climatic patterns in the past.

Aside from the work of Petersen (1988), not one of the aforementioned analyses from montane environments has focused primarily on the late Holocene period, particularly the last 1,500 years. Instead, most of these efforts have been oriented toward geological and ecological processes spanning long periods to identify broad patterns associated with climatic transitions between the Pleistocene and Holocene epochs, which are often associated with deglaciation from Holocene warming as evidenced by successional responses of vegetation assemblages. With the exceptions of Fall (1997b) and Petersen (1988), these palynological investigations have concluded that temperature patterns for the past 2,000 years in western Colorado have remained relatively stable. Moreover, previous research, including that of Petersen (1988), may have underemphasized minor climatic oscillations by using relatively low-resolution sampling strategies consisting of samples that are spaced every 5 cm or more, often with unequal intervals. Temporal resolution, as a result, is often on a scale of hundreds of years (Butzer 1982; Dincauze 2000), whereas the local archaeological record is tied to tree rings and has an effective resolution of years to decades.

Our knowledge of cultural change and settlement dynamics in the Mesa Verde region has expanded significantly since Petersen's (1988) remarkable paleoclimatic reconstruction, primarily through the work of Crow Canyon Archaeological Center. Due to these recent advances, it has become imperative to refine Petersen's low-frequency paleoclimatic reconstruction to identify climatic changes of lesser magnitudes and at smaller scales. The identification of minor climatic oscillations is critical for inferring differences in subsistence potential that are temporally similar in scale to the periods recognized in the archaeological record. The Village Project, for example, recognizes 14 periods from A.D. 600 - 1300, with an average length of about 50 years (s = 25 years) (Kohler et al. 2006:Table 1). As an attempt to identify relatively slight oscillations, on a time scale more compatible with that recognized in the local archaeological record, I sampled the peat-bog record at Beef Pasture every other centimeter, which, as we will see, yields a temporal interval between samples of about 30 years – an average temporal precision higher than that recognized in the archaeological record.

Previous research has also been of low utility to archaeological research because there is a dearth of chronological control for deposits from the late Holocene in these studies. As Hevly (1988) points out, only a few of the numerous palynological studies from the Four Corners region have yielded results that are dated either archaeologically (relatively) or radiometrically (absolutely) to the last 2,000 years. Therefore, their ability to provide a dynamic environmental context for the most-studied period in Southwest prehistory is limited. While Petersen's research (1988) provides the best temporal resolution for the past 2,000 years of any locally relevant palynological studies, his chronological control for this period is based solely on two ^{14}C dates and one relative date inferred from palynological evidence of historical activity. Petersen's two radiometric dates bracket the period relevant to my study, and these dates with known depths-below-surface provided an excellent opportunity to re-core at Beef Pasture to a depth known to include deposits dating from A.D. 600 - 1300 and to re-sample organic matter for additional ^{14}C dates within this period. This earlier work has made it possible for me to report, and use for chronological control, 16 radiocarbon dates from the past 2,100 years as well as a modern surface date.

In the remainder of this thesis I provide a detailed discussion of the methods and analysis I used to reconstruct the paleoclimatic patterns over the past 2,100 years in the northern San Juan region. In Chapter 2 I outline the geology of the study area, its vegetation, and the possible impacts historic activities may have had on this area's sedimentology and vegetation, which could have affected the types of pollen deposited and their preservation at Beef Pasture. I then detail how the pollen of certain species, referred to here as indicator taxa, serve as reliable proxies for paleoclimatic changes in Chapter 3. In Chapter 4 I lay out the methods I used for collecting, processing, and analyzing the pollen and radiocarbon samples that I use to reconstruct changes in the region's paleoclimate. I present the results of these analyses in Chapter 5, where I describe how I created a deposition rate for calculating pollen influx rates and assigning each pollen sample and estimated calendrical date. I also present here the methods used for dividing the pollen sequence into zones and discuss the various quantitative measures employed to identify significant paleoclimatic changes.

I interpret the results of my analysis in Chapter 6, where I present a two-part discussion. The first part entails a comparison of the various proxies across zones to identify statistically significant changes in climatic variables. I then compare these results to those of other paleoclimatic reconstructions from the region, including those derived from both tree-ring and pollen records. In the second part I compare the Village Project's paleodemographic reconstruction to the paleoclimatic reconstruction presented here, which identifies many major demographic fluctuations that corresponded with major perturbations in the region's climate. I suggest that these demographic processes, therefore, may have been in response to these low-frequency climatic changes due to their effect on regional agricultural potential. This comparison, however, is tentative because the low-frequency paleoclimatic reconstruction presented here has yet to be incorporated into the Village Project's paleoproductivity model. Furthermore, while the temporal resolution of this paleoclimatic reconstruction conforms well to that of the archaeological record, significant within-zone paleoclimatic fluctuations cannot be verified statistically.

CHAPTER TWO

STUDY AREA

In this chapter I discuss the relevant geographic, geological and environmental contexts of the La Plata Mountains and the coring location. Here, I place emphasis on the vegetation of the La Plata Mountains, primarily the dominant species within the mountains that are likely contributors to the pollen deposited at the coring location. A review of historical activity around Beef Pasture brings to light the possibility of disturbance to the sediments and pollen used in this study. These effects are shown later to be minimal and restricted to the uppermost deposits.

La Plata Mountains, Southwestern Colorado

The La Plata Mountains (Figures 2 and 3) are located in the San Juan National Forest at the juncture of the Colorado Plateau and the San Juan Mountains in southwest Colorado. This mountain group extends into the eastern edge of the Colorado Plateau 30 km (20 mi) southwest of the actual San Juan Mountain front. The La Plata Mountains are one of four structural domes along the western margin of the San Juan Mountains that formed as a result of plutonic intrusions into overlying sedimentary bedrock. This sedimentary bedrock has subsequently eroded along fault blocks and fracture zones, resultant from warping along the western flanks of the San Juan uplift, to expose these plutonic intrusions (Blair et al. 1996; see also Cross et al. 1899; Eckel et al. 1949; Haynes et al. 1972; Holmes 1877:268-272). The plutonic intrusions that originally formed the mass of the La Plata Mountains occurred between 65 and 67 million years ago (Cunningham et al. 1977). Subsequent geological intrusions consisted of igneous dikes, sills and stocks, of which the formations now called Burro Mountain, Helmet Peak, Hogback Ridge and Sharkstooth Ridge are comprised. The Dolores River watershed drains the north side of the La Plata Mountains whereas the San Juan River watershed drains the south side. Both of these

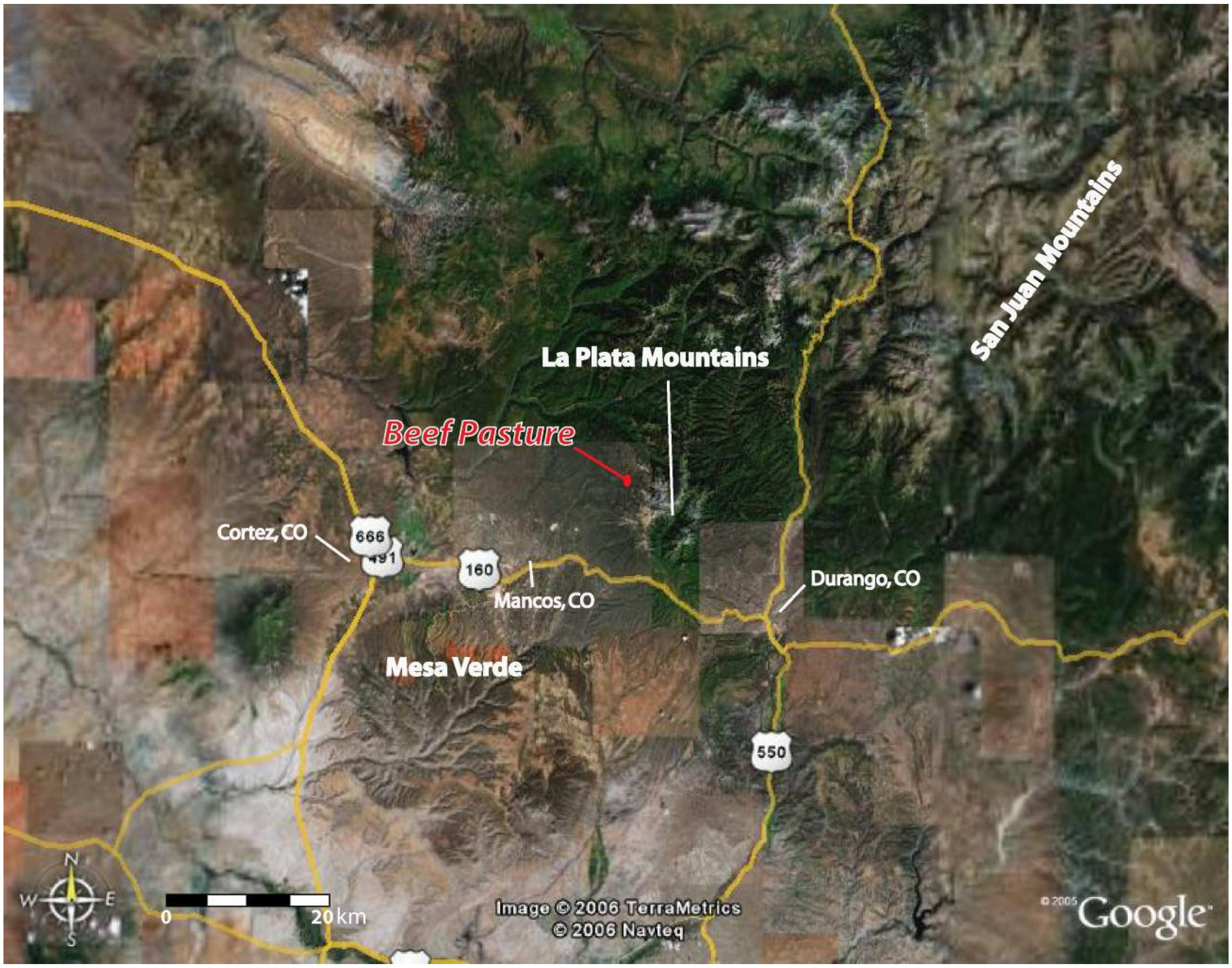

Figure 3. Google Earth® image of southwestern Colorado showing Beef Pasture in relation to modern settlements and topographic features discussed in text.

rivers and their tributaries, along with their floodplains, supported relatively large communities of agriculturalists with water and farmland during Ancestral Puebloan occupation of the region.

The 2,700 m (8,850 ft) elevational change between the San Juan River and the highest peaks in the La Plata Mountains results in very different climate regimes at the base of and on top of the mountains. These elevationally dictated climate regimes strongly influence the type and abundance of vegetation at any point along the gradient. Eckel et al. (1949:5), Cross et al. (1899:2) and Steinhoff (1976) provide brief descriptions of the vegetation in the La Plata

Mountains. More extensive mapping and descriptions are available for the adjacent San Juan Mountains and between Durango and Pagosa Springs, Colorado (Krebs et al. 1976; Maher 1961:16-20, 1963:148-149). Brown (1982) also provides a description of the biotic communities in the region, including the distribution of vegetation and fauna across landscapes. In a broader sense, the vegetational assemblages of both the La Plata and San Juan Mountains are typical of the Southern Rocky Mountains (Alexander 1974; De Velice et al. 1986; Peet 1978).

Petersen (1988:12-14) divides the La Plata Mountain vegetation into four zones (Figure 4) based on their arboreal compositions, and I use his classification here to facilitate comparisons to studies by Petersen and others from the region. The alpine zone begins at the spruce-fir tree-line (3,500 to 3,700 m [11,500 to 12,000 ft], depending on aspect) and extends upward to the mountains' peaks (a maximum elevation of 4,030 m [13,232 ft] at Hesperus Peak). Tree-line is defined here as the elevational limit of erect trees taller than 4 m (13 ft) (Little 1979). The alpine zone is characterized by a lack of arboreal vegetation due to dense snowpack and shallow soil deposits. However, the lower limit of the alpine zone, approximately 100 to 150 m (325 to 500 ft) above the tree-line, contains trees that are *krummholz* (German for 'crooked wood') in form; such trees are environmentally dwarfed types that grow as regular trees in more hospitable climates (Wardle 1974) in the subalpine forest. The biological processes that result in *krummholz* forms are discussed in LaMarche and Mooney (1972:69-70), Tranquillini (1979:102-111) and Wardle (1965:127-128, 1968, 1974:378-388). The upper elevation where *krummholz* trees terminate is called the timber-line in contrast to the spruce-fir tree-line as defined above. The subalpine zone begins near 3,050 m (10,000 ft) in elevation and extends upward to the spruce-fir tree line. The arboreal vegetation of this zone is comprised largely of Engelmann

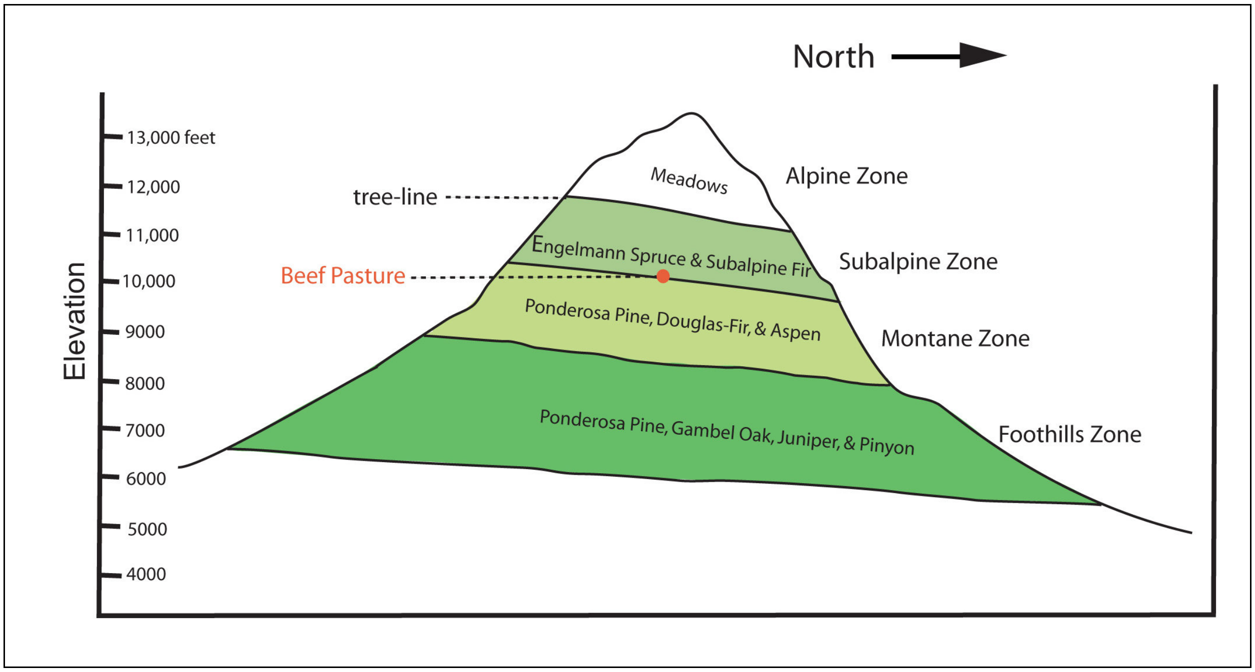

Figure 4. La Plata vegetation zones highlighting dominant overstory species by elevation (adapted from Krebs et al. 1976:Figure 1; Maher 1961:Figure 2; Petersen 1988:Figure 4).

spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*) and stands of quaking aspen (*Populus tremuloides*) that envelop numerous subalpine fens, such as Beef Pasture. The montane zone begins roughly at an elevation of 2,500 m (8,200 ft) and extends upslope to the base of the subalpine zone. This zone contains a mixed-conifer forest composed of the following species (in order of abundance): Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), quaking aspen, white fir (*Abies concolor*), limber pine (*Pinus flexilis*), blue spruce (*Picea pungens*) and subalpine fir. The foothills zone begins at an elevation of 1,900 m (6,200 ft) and extends upward to the base of the montane zone; it is comprised largely of ponderosa pine and Gambel oak (*Quercus gambelii*). While ponderosa pine is located in the montane zone as well, it is most prolific in the foothills. Likewise, Gambel oak extends into lower elevations. The lower portion of the foothills zone, below 2,200 m (7,200 ft), begins to blend with the lower elevational plains zone, thus it commonly contains pinyon pine (*Pinus edulis*), Utah juniper (*Juniperus osteosperma*), Rocky Mountain juniper (*Juniperus scopulorum*) and Gambel oak.

Although Petersen (1988:12-14) does not refer to vegetation below the foothills zone as comprising a zone of the La Plata Mountains (these elevations are not actually in the mountain range), the vegetational assemblage from these elevations is considered here as the plains zone for classificatory purposes. Newberry (1876:84) describes the area extending from Mesa Verde west to Comb Ridge as the "Sage Plain" due to the abundance of Great Basin sagebrush (*Artemisia tridentata*; also known as big sagebrush) in this area. The Sage Plain is actually a dissected plateau with an area of 3,100 km^2 (1,200 mi^2) and ranges in elevation from 1,500 to 2,200 m (4,900 to 7,200 ft) (Gregory and Thorpe 1938:7, cited in Petersen 1988:14). Aside from Great Basin sagebrush, the plains zone also supports pinyon pine, Utah and Rocky Mountain junipers and the occasional grove of Gambel oak. Most of the extra-local pollen grains in the pollen rain of the La Plata Mountains probably originated in this area given the west-to-east and northwest-to-southeast winds prevailing today.

Beef Pasture, La Plata Mountains, Colorado

At present, Beef Pasture (S$_{1/2}$ SW$_{1/4}$, Section 11, Township 37 North, Range 12 West, Rampart Hills Quadrangle, Colorado; 37º 28' 20" north, 108º 9' 30" east) is a relatively open, 75-hectare (8,072,933-ft^2) meadow with a southwest-facing aspect on the west slope of the La Plata Mountains (Figures 5 and 6). Positioned near the drainage divide between the San Juan and Dolores River watersheds, Beef Pasture is about 25 km (15 mi) northwest of Durango, Colorado (Figure 3). The western portion of the La Plata Mountains above 2,400 m (7,875 ft) is composed largely of Mancos Shale (Cross et al. 1899; Haynes et al. 1972), a soft and friable clay-shale formation. The topographically depressed nature of Beef Pasture, which has created

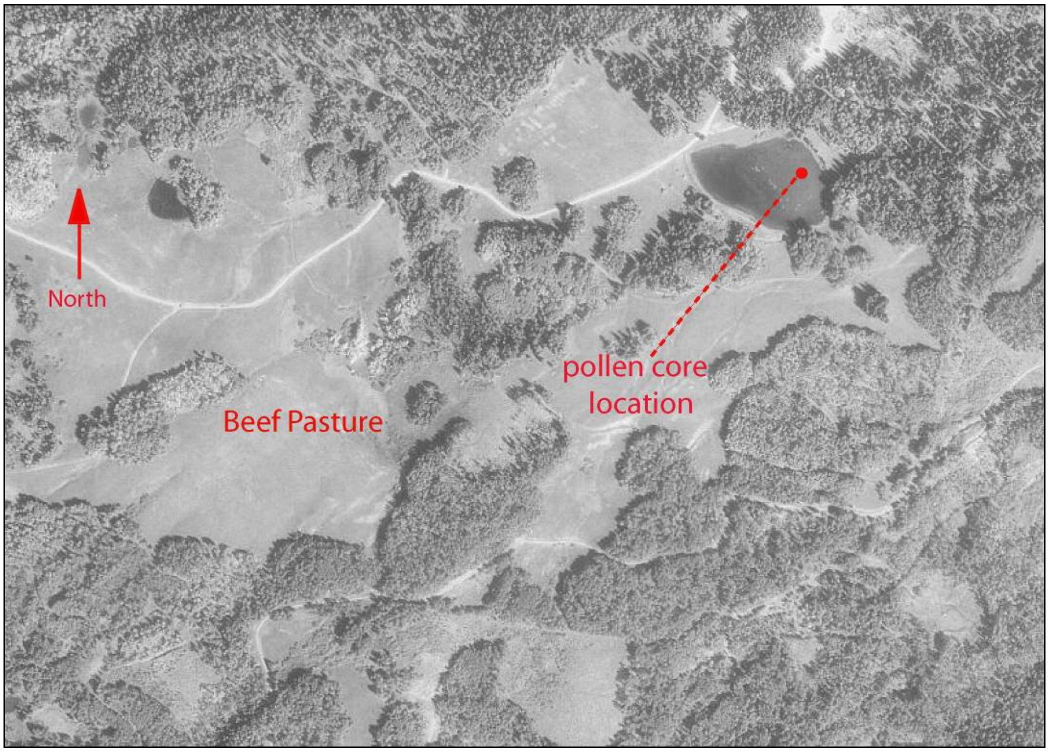

Figure 5. Aerial photograph of Beef Pasture, La Plata Mountains, southwestern Colorado in 1994 showing pollen core location (picture courtesy of the U.S. Geological Survey). Darker-colored trees near top of picture are Engelmann spruce (subalpine forest zone) while the lighter-colored trees in bottom portion of picture are ponderosa pine (montane forest zone). Note the relationship of Beef Pasture and the pollen core location to the transition between the forest zones. Note further that the pollen core location is periodically inundated by standing water (as in the picture), however, the standing water was located approximately 35 m west of this location when we cored in August 2005.

its perennially wet meadow, is the result of a landslide that occurred *circa* 5,500 years B.P. (Petersen and Mehringer 1976:277). Higher elevation landslides in this region, such as the one that created Beef Pasture, are often the result of more resistant rock sliding over the Mancos Shale (Atwood and Mather 1932:146-164). When the Mancos Shale is exposed, it is permeated by groundwater and runoff, which lubricates glide planes and adds weight to the more resistant rock atop the shale. As a result, landslides occur and leave crescent-shaped depressions that later become marshes, fens and oval ponds. At Beef Pasture, the sediments that subsequently in-filled

Figure 6. Google Earth® image of Beef Pasture, La Plata Mountains, southwestern Colorado showing location of peat bog and provenance of pollen-core used in this study (Core No. 3).

this depression are comprised mostly of sedge peat, with a 17-cm thick band of silty detritus *gyttja* (Swedish for 'a nutrient-rich sedimentary peat') interbedded within the peat at approximately 3.3 m below surface, which in turn overlies accumulations of sand, silt and clay formed immediately after the landslide (Petersen 1988:Table 2).

The elevation of Beef Pasture (3,060 m [10,040 ft]) is just above the approximate elevation of the present-day division between the subalpine and montane forest zones (Figures 4, 5 and 7). The peripheral overstory at Beef Pasture is currently composed of Engelmann spruce,

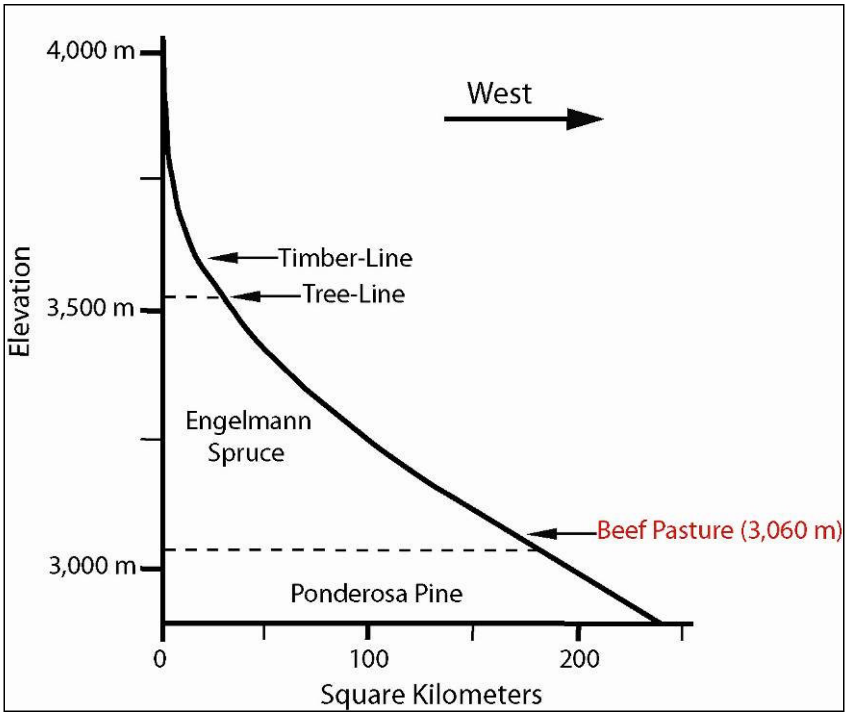

Figure 7. Area-elevation graph of the western front of the La Plata Mountains (adapted from Petersen 1988:Figure 28; Petersen and Mehringer 1976:Figure 10). Note Beef Pasture's location near the boundary of two forest zones.

Douglas-fir, quaking aspen and alder (*Alnus tenuifolia*). Although willow (*Salix* sp.) is generally considered an arboreal genus, the species at Beef Pasture, *Salix brachycarpa*, is a short deciduous shrub located near the edges of the wet meadow, hence the common name of 'barren-ground willow.' Aside from barren-ground willow, common understory plants located presently around Beef Pasture are goosefoot (*Chenopodium fremontii*), yarrow (*Achillea lanulosa*), Rocky Mountain goldenrod (*Solidago multiradiata*), Coulter's daisy (*Erigeron coulteri*), aspen fleabane (*Erigeron speciosus*), beaked sedge (*Carex utriculata*), small-winged sedge (*Carex microptera*), western marsh marigold (*Caltha leptosepala*) and several species of grass (Poaceae) and mosses (*Brachythecium* sp., *Aulacomnium* sp. and *Drepanocladus* sp.).

Although it is unlikely that direct anthropogenic disturbance occurred at Beef Pasture in the prehistoric record, at least at a magnitude that would significantly alter the local forest composition and sedimentology, the area has witnessed considerable sedimentological and vegetational disturbance in the recent past from mining, logging, settlement, fire, grazing, recreation and water acquisition. Petersen (1988:55) provides a brief review of these historic events. Mining activity in the area began in 1869 with prospecting in the headwaters of the Mancos River (Larsen and Cross 1956:3). Hundreds of mining claims were reported between 1873 and 1909 and over 200 were granted, although none of these is known to have included Beef Pasture or the land immediately adjacent to it. The railroad system expanded west to Durango in 1881, and the La Plata Mountains, and alpine fens like Beef Pasture in particular, became important locales for summer grazing of cattle and sheep. By the 1890s, considerable logging activity began in the Mancos area, and E. C. Cooper established a sawmill at Beef Pasture *circa* 1900. Cooper worked at Beef Pasture briefly, and then moved his operation to Spruce Mill Park, where he bobsledded timbers through Beef Pasture and on to Transfer Park (now known as Transfer Campground) (Ellis 1976:187).

There is no documentation on what occurred around Beef Pasture between 1900 and 1940, however, logging, grazing, mining and recreation probably continued near or in the fen. On October 8, 1940, Sherron Spencer was granted a special use permit to construct Spencer Reservoir (Tim Kohler, personal communication 2006, citing McCoy n.d.). Construction of the reservoir began in the early 1940s and consisted of a 2.74-m (9-ft) earthen dam that created a 5-acre (217,800-ft^2) pool of standing water; this reservoir serviced the Spencer Water System, a privately owned irrigation company that supplied water to farmers down the West Mancos River. The headworks of the reservoir were damaged in 1967, which caused a breaching of the dam and a complete draining of Spencer Reservoir. The dam was reconstructed in 1973 to a height of 4.2 m (13.8 ft) and relocated 6.1 m (20 ft) downstream. Spencer's permit was terminated in 1978 because the construction activity in 1973 was not in conformance with Colorado statutes. Additional enlargements of the earthen dam were nevertheless undertaken in 1991 by Jim Spencer, a nephew of Sherron Spencer, but the extent of that remodeling is unknown. A recent palynological project at Beef Pasture (Wright and Petersen 2005) concluded that over 2 m of sediment had been removed from where Petersen and Mehringer (1976) had cored in 1973, just prior to reconstruction of the dam. The fact that this volume of sediment has been dislocated suggests that mechanical operations, probably with a bulldozer, occurred in 1973, 1991, or both years. The original construction of the dam in the 1940s suggests that mechanical disturbance occurred at this time as well.

Inspection of the area during coring for this project provides additional contextual data on recent disturbance in the area. Remnants of several campfires at Beef Pasture are located just south of an east-to-west trending graded dirt road (San Juan National Forest Road #350) that traverses the northern edge of the meadow. I also observed sheep grazing in the area, and several pieces of modern trash within Beef Pasture suggest continued use of the area by campers, hunters and other recreationalists. The current level of the reservoir seems much lower than what has been documented in the past, where the edge of the standing water was located approximately 10 m (32.8 ft) downslope of Petersen and Mehringer's (1976) coring location in August of 2005. This lower water level is most likely related to the shifting location of the earthen dam that occurred in 1973 and differences in the season of coring activities because this water level likely fluctuates both seasonally and annually with different precipitation and evaporation rates. Figures 5 and 6 display different water levels likely due to differences in the years and seasons of photographic documentation.

Given that cattle use Beef Pasture for grazing and to access the water tank, it is possible that they have disturbed the uppermost deposits in and around the fen. Consistent trampling of the sediments and the uprooting of grasses and shrubs can disturb the depositional sequence of pollen in Beef Pasture. Beef Pasture sediments, however, consist mainly of woody sedge peat, and the fibrous nature of this sediment enables it to support the weight of cattle without their hooves puncturing the ground surface to any large extent. If cattle have altered the pollen deposition at Beef Pasture, I expect it to be maintained to the uppermost sediments.

In the next chapter I discuss ways in which pollen of various species in the La Plata Mountains can serve as proxies for paleoclimatic changes.

CHAPTER THREE

PROXIES FOR PAST CLIMATIC CHANGE

In this chapter I outline which plant species in the La Plata Mountains are sensitive to climatic fluctuations and how changes in the deposition of their pollen serve as reliable proxies for fluctuations in certain climatic variables. I start with a review of how previous analysts have used the pollen of arboreal species to identify shifts in tree-lines, which imply changes in either winter precipitation or temperature. I then discuss how the pollen of understory plants can serve as an independent proxy for winter precipitation, which allows me to differentiate between temperature and winter precipitation as the causal force of change in the arboreal structure of the subalpine forest.

Studies that utilize alpine pollen assemblages to infer prehistoric fluctuations in regional temperatures typically rely on frequencies, influx rates and ratios of the tree species that demarcate regional tree lines (e.g., Andrews et al. 1975; Fall 1985, 1988, 1997b; Feiler et al. 1997; Maher 1961, 1963, 1972a; Markgraf and Scott 1981; Pennack 1963; Petersen 1988; Petersen and Mehringer 1976; Short 1985; Vierling 1998). The basic assumption in such analyses is that tree-lines move in tandem with the elevation of a particular summer isotherm (Arno 1984: Daubenmire 1943a, 1943b, 1954; LaMarche 1973; Scuderi 1987), therefore, changes in the elevation of the tree-line indicate changes in the elevation of this isotherm. The climatic oscillation causing such movement is then extrapolated into a regional context. A lowering of the elevation of the isotherm is inferred to also affect temperatures at lower elevations and within a given region. A lowering of the isotherm's elevation results in reduced temperatures within the region as a whole, and it affects not only the maximum summer temperatures but also the annual temperature patterns. Thus, a lowering of the elevation would reduce summer temperatures as well as the temperatures of the other seasons. The converse of this relationship is also at play; increases in the elevation of the isotherm result in higher annual temperatures within a region.

From a palynological perspective, I would expect that tree-line fluctuations would result in changes in the pollen ratio of the tree-line species to other taxa; increases in the tree-line pollen would indicate succession of the tree-line upslope, and vice versa. Such palynological investigations provide a unique analytical approach to analyzing low-frequency temperature change; they differ from many other palynological analyses because tree-line movement studies generally focus on the ecological preferences of a select few taxa (a method often referred to as the ‘indicator-species approach’ [see Birks 1973; Birks and Birks 1980; Janssen 1967, 1970, 1981]), not on the entire vegetational assemblage.

Engelmann Spruce as Temperature Indicator

In the alpine settings discussed in this thesis, gross temperature fluctuations are observable in the duration of snowpack and its effect on the reproductive success and annual production of local plant taxa (Billings and Bliss 1959; Canaday and Fonda 1974; Emerick and Webber 1982; Fareed and Caldwell 1975; Holway and Ward 1963; Steinhoff 1976). Movement in elevation of the lower boundary of the spruce-fir forest is dependent on conditions of the snowpack deposited from late fall to early spring (Daubenmire 1954:128-129; Dix and Richards 1976; LaMarche 1973:637; Lindsay 1971:Table 1; Marr and Marr 1973; Pearson 1931:Figures 14 and 15; Wardle 1968:Figure 3). Duration of snowpack at a particular elevation is the most critical non-geological determinant of whether or not Engelmann spruce will grow at that elevation. The root system of Engelmann spruce is usually less than 50 cm in depth (Pearson 1931:64), which contributes to its ability to grow in the shallow soils near the upper subalpine forest tree-line. Due to its shallow root system, Engelmann spruce is more prone to adverse affects from drought and heat than many other alpine species (Daubenmire 1943a:10-12; Pearson 1931; Wardle 1968:Figure 6), and the lower elevational limit of this species is largely determined by deficient soil moisture (Daubenmire 1943a:365-372; Pearson 1920:306).

Downslope movement of spruce trees is obviously dependent on dispersion of seeds and their ability to produce viable seedlings that can establish themselves and survive. Spruce seeds are set in autumn and lie dormant under snow throughout the winter. By late spring the snow has usually melted and the upper portion of the soil begins to dry and warm quickly. Spruce seeds, given their small size, do not contain very high reserves of nutrition or moisture, and if the early summer rains are either delayed or deficient then the seeds will desiccate and not produce seedlings. If the seeds do not germinate until after the monsoonal season in late summer, Ronco (1967:5) argues that seedlings will not have enough time to establish themselves adequately prior to the cold weather of autumn and winter. According to Alexander and Nobel (1971), spruce seedlings can survive with a minimum of 25 mm (1 in) of well distributed monthly precipitation, mostly during summer months when there is no snow cover. If less precipitation falls during these months, there is a heightened chance that soil drying will prevent the penetration of the seedling’s radicles, which would result in the untimely death of the seedling (Day 1963, 1964; Day and Duffy 1963:25).

While summer precipitation is essential to the establishment of seedlings on a yearly basis, duration of snowpack is actually more critical to the distribution of spruce along the lower boundary of the subalpine forest. Dix and Richards (1976:311) observed that spruce predominates where the duration of snowpack is the longest, whether as a result of increased winter precipitation, decreased temperatures, or geographic aspect. This is probably because summer precipitation in the subalpine forest is generally higher than the required 25 mm (1 in) each month that Alexander and Nobel (1971) suggest. Modern precipitation records from southwestern Colorado weather stations suggest that regional elevations higher than 2,134 m (7,134 ft) average 244 mm (9.6 in) of precipitation between May and September (Adams and Petersen 1999:23; Bradley and Barry 1973), or 48.8 mm (1.9 in) per summer month. Although deficiencies in summer precipitation can be detrimental to seedlings, the existing root systems of fully grown trees can withstand such shortfalls. As a result, seedlings may not survive from year to year, but fully grown trees can persist and deposit seeds in following years that can develop into fully established seedlings provided that summer precipitation deficiencies are not recurrent. I expect the lower subalpine forest border to shift upslope due to reductions in summer precipitation only if deficiencies were extreme and prolonged over many years, and it would therefore be a response to low-frequency climatic change.

Although spruce pollen (Figure 8), like that of all gymnosperms, is anemophilous (dispersed by wind), the distance of dispersal tends to be geographically restricted due to its high fall-out rate (Dyakowska 1937), which is in turn due to its large size. Maher (1961, 1963) is often credited for recognizing the short distances for spruce pollen dispersal; however, his measure was more qualitative than quantitative. Janssen (1966:816) agrees that the dispersal of spruce is “poor” because it does not travel very far and is thus a poor indicator of regional conditions. Jonassen’s research (1950) provided the first actual quantification of spruce pollen dispersal distance. He noted that spruce pollen comprised 59 percent of the pollen sum at the Norway spruce (*Picea abies*) forest border and only 7 percent of the pollen sum from a sample 200 m (600 ft) upslope of this border. Following up on this study, Wright’s research (1952) determined that 68 percent of Norway spruce is deposited within 30 m (100 ft) of its source and

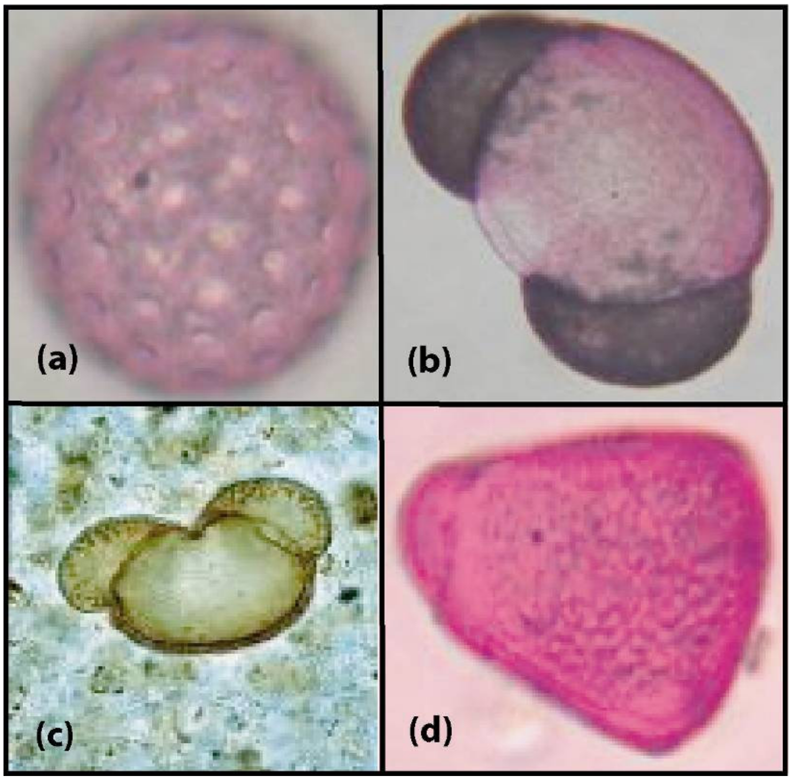

Figure 8. Binocular microscopic images of indicator pollen-types discussed in text. (a) Cheno/Am with a size range of 20 - 30µ (from Hoffman 2006), (b) spruce with a size range of 75 - 125µ (from Hoffman 2006), (c) pinyon pine with a size range of 50 - 60µ (from Jacobs 2006), (d) sedge with a size range of 30 - 40µ (from Hoffman 2006).

only 7 percent at 100 m (330 ft) from its source. King (1967) reported that the downslope dispersal of Engelmann spruce in the Sandia Mountains of New Mexico was less than 120 m (400 ft), and one should expect similar dispersal patterns for this species in the La Plata Mountains.

Considering that Engelmann spruce pollen tends to be deposited so close to the source tree, significant changes in its deposition at Beef Pasture should relate to the proximity of the source trees to the sampling location. In fact, an area elevation graph around Beef Pasture (Figure 7) demonstrates that a 100-m (328-ft) upslope movement of the lower boundary of the subalpine forest would place Beef Pasture approximately 60 m west of this boundary; such a shift would undoubtedly result in considerably less deposition of spruce pollen at Beef Pasture, especially when one considers that wind would tend to disperse this pollen eastward and away from Beef Pasture. I suggest, therefore, that measures of spruce pollen frequency and influx will help identify local movements of the lower subalpine forest boundary (comprised largely of Engelmann spruce).

Since snowpack duration determines the elevation of the lower boundary of the subalpine forest, and since this forest zone is comprised largely of Engelmann spruce, a reduction in this duration would seemingly result in upslope movement of this boundary, and vice versa. Snowpack duration at any elevation, however, is controlled by two factors: the amount of winter precipitation and the rate at which snowpack melts. The rate at which snowpack melts is directly related to annual temperature patterns; colder temperatures reduce the melt rate and result in longer durations of snowpack. Winter precipitation rates dictate the amount of snowpack at a particular location, with increased winter precipitation resulting in more snowpack, and thus a longer duration of snowpack. Therefore, while frequency, ratio and influx measures of the pollen of particular tree species allow inferences on the movement of the lower boundary of the subalpine forest, uncoupling the climatic cause(s) of the change in snowpack duration requires the use of other taxa indicative solely of either the amount of winter precipitation or temperature. As Fall (1997b:1307) notes, studies reliant on the movement of tree-lines usually result only in qualitative measures of “warmer and wetter” or “colder and drier”; this study attempts to isolate the winter precipitation regime from the regional temperature patterns. A comparison of the fluctuations in spruce pollen measures to those of an independent proxy for winter precipitation, discussed below, allows me to uncouple these two climatic variables.

Sedge and Cheno/Am as Winter Precipitation Indicators

The ability to isolate periods of increased winter precipitation from those of decreased temperature, as evidenced by the downslope movement of the lower boundary of the subalpine forest, may reside in the changing ratio of sedge (*Carex* sp.) to Cheno/Am pollen types as well as significant changes in the influx rates of these taxa through time. Here, Cheno/Am refers to a palynological classification for a combination of various plants belonging to either the Chenopodiaceae family or the *Amaranthus* genus whose pollen grains are indistinguishable with binocular microscopes. Inability to differentiate these pollen-types in this study does not hinder my analysis because local species in these taxa favor similar environments and climates.

Local varieties of sedge (beaked sedge and small-wing sedge) are indicative of wet and waterlogged sediments and are characteristic of Rocky Mountain alpine fens (Herman 1970); changes in their frequency should be related to water-table fluctuations resulting from fluctuating precipitation regimes. Due to morphological similarities in the pollen of these two species of sedge, and others common to regional alpine fens (i.e., *Carex aquatilis*), I was unable to identify sedge pollen to a particular species. Beaked sedge (*Carex utriculata*), small-wing sedge (*Carex microptera*) and water sedge (*Carex aquatilis*), however, tend to be part of the same vegetation community (Cooper 1986) and are thus indicative of similar environmental and climatic conditions. Moreover, the habitat of beaked sedge tends to be low in species diversity and this species characteristically dominates the assemblage for long periods provided environmental and climatic factors remain favorable (Chade et al. 1989; Hansen et al. 1990).

Much less is known about the dispersal of sedge pollen (Figure 8) than that of spruce. Locally occurring sedge species are also anemophilous but appear to have relatively confined dispersal patterns. Since these species are located within the forest’s understory, the dispersal of their pollen should be expected to be restricted to within a few meters of the source (Handel 1976). As a component of the understory, sedge pollen dispersal is likely to be restricted to the trunk space component (Tauber 1965); pollen in this component does not travel very far because it is filtered from the air by tree trunks, tall vegetation and other obstacles to aerial transport. Given these dispersal patterns, sedge pollen in the Beef Pasture pollen profile should reflect locally occurring sedge species in the immediate vicinity of Beef Pasture.

Unlike spruce, the biological processes of sedge germination are poorly understood and have therefore been the result of several recent ecological and range management studies (e.g., Cooper and MacDonald 2000; Jones et al. 2004; Vellend et al. 2000). While germination is understudied, the environmental and hydrological preferences of established beaked sedges demonstrate how this taxon can be useful for inferring changes in winter precipitation. Controlled field experiments on the survival of greenhouse-germinated seedlings suggest that beaked sedge is more likely to survive in wet sites (Cooper and MacDonald 2000). Beaked sedge prefers sites that flood in the spring and early summer, and can thrive in water standing up to 16 inches deep (Pearle 1996). After lying dormant through the winter months, beaked sedge begins to regreen and grow in early spring (Bernard and Brown 1977; DeBenedetti and Parsons 1984; Pierce and Johnson 1986) as winter snows melt. Beaked sedge flowers from June to August, depending on location (Dittberner and Olsen 1983), just after the snow melt of spring; therefore, the deposition of this species' pollen should follow winters where precipitation was adequate to allow growth. Since beaked sedge lives for only 2 to 6 years (Bernard and Brown 1977; Pierce and Johnson 1986), this species' pollen deposition should fluctuate significantly through time. These high-interval fluctuations, however, should be temporally subsumed into periods represented by each pollen sample, here 25 to 30 years, and thus reflect the low-frequency patterns that I intend to elucidate.

To date, there have been few attempts to correlate winter precipitation with changing frequencies of sedge pollen in subalpine forests. Several researchers (Fall 1985, 1988, 1997a; Vierling 1998) have viewed sedge frequencies as indicative of wetter or drier meadow conditions, however they have not directly linked these changes with winter precipitation. Vierling (1998) compared sedge pollen frequencies to those of Cheno/Am to differentiate perennially wet meadows from seasonally dry meadows; reduced sedge frequencies with increased Cheno/Am frequencies indicate seasonally dry meadows, and vice versa. Vierling selected Cheno/Am frequency because it is characteristic of disturbed environments, such as seasonally flooded dry meadows. Aside from Vierling's (1998) study, this thesis is the only paleoenvironmental reconstruction from the region that is reliant on sedge, and it differs from all others by using sedge and Cheno/Am pollen (Figure 8) as indicators of qualitative changes in winter precipitation.

Pinyon Pine as Summer Precipitation Indicator

The physiological structure of pinyon pine suggests that its pollen deposition can serve as proxy for low-frequency fluctuations in summer precipitation. Fritts et al. (1976:107-109) demonstrate that pinyon trees have shallow root systems and deep taproots, and that this structure is adapted to seasonal variability in precipitation. During the spring and early summer, the deep taproot allows the tree to access deep soil moisture originating from winter precipitation. Once this is depleted, usually by May or June, the shallow roots are able to capture moisture from summer thunderstorms that are intense but do not permeate deeply into the ground. Research on seedling physiology also suggests that pinyon is well adapted to spring droughts and summer thunderstorms. The pinyon pine's large seed provides this species with a rapid rate of establishment, where radicle penetration, cuticle thickening and needle development occur relatively quickly (Daubenmire 1943a:11; Emerson 1932; Wells 1979:318).

Petersen used pinyon pine pollen influx rates as a proxy for changes in low-frequency patterns of summer precipitation, arguing that these changes are primarily influenced by dynamic jet stream relationships (Petersen 1988:83-94). To demonstrate such a relationship, Petersen (1988:Figures 45 and 46) compared historic pinyon pine tree establishment with summer precipitation records from the Mesa Verde region. This comparison indeed demonstrates a correspondence between historical pinyon pine distribution with summer precipitation patterns, a conclusion also found in other studies (e.g., Betancourt 1984; Cole 1982; Markgraf and Scott 1981; Van Devender et al. 1984; Wells 1979). Petersen (1988) further compared the historic influx rate of pinyon pine pollen in the La Plata Mountains with the number of pinyon pine trees known to have existed at lower elevations during this period. His results demonstrate a correspondence between pinyon pine tree distribution and the influx rate of pinyon pine pollen in the La Plata Mountains, and thus a relationship between pinyon pine pollen influx and summer precipitation patterns. This study thus assumes that changes in the influx rate of pinyon pine pollen (Figure 8) represent changes in the number of pinyon trees at lower elevations in the Mesa Verde region (below 2,200 m [7,200 ft] in the foothills zone), and by extrapolation, these changes in pinyon tree abundance are posited as resulting primarily from low-frequency fluctuations in summer precipitation.

Based the climatic parameters and pollen dispersal patterns for the indicator taxa discussed above, I argue here that fluctuations in each indicator taxon's pollen reflect changes in the associated climatic variables. Table 1 provides a summary of the expected response of each

Table 1. Expected Changes[a] in Indicator Taxa Pollen in Response to Climatic Fluctuation

Climatic Variable	Fluctuation	Spruce[b]	Sedge	Cheno/Am	Pinyon Pine
Annual Temperature	Increase	Lower	-	-	-
	Decrease	Higher	-	-	-
Winter Precipitation	Increase	Higher	Higher	Lower	-
	Decrease	Lower	Lower	Higher	-
Summer Precipitation	Increase	-	-	-	Higher
	Decrease	-	-	-	Lower

[a] measured as changes in the percentage of total pollen sum, pollen influx rates, and pollen ratios between indicator taxa (see Chapter 5)

[b] spruce fluctuates in response to both temperature and winter precipitation; a comparison to changes in sedge and Cheno/Am pollen deposition allows for a differentiation between the two climatic variables

indicator taxon under given climatic changes as measured through the deposition of their pollen at Beef Pasture. Therefore, I interpret significant fluctuations in the measures of each indicator taxon's pollen as changes in the associated climatic variable.

In this chapter I made a case for how the pollen from the indicator taxa serve as proxies for low-frequency fluctuations in the climatic variables that affect a region's agricultural potential, as discussed in Chapter 1. In the following chapter I outline the methods used for collecting and analyzing pollen and radiocarbon samples from Beef Pasture.

CHAPTER FOUR

METHODS

Here, I detail the methods involved in collecting the sediment core, the processing of both pollen and ^{14}C samples, and the identification of pollen types. While these methods may differ slightly from those of other palynologists, they do follow established standards. I selected the pollen-processing techniques used here to ensure that the recovered pollen assemblage is an accurate representation of the pollen deposited in the past and to minimize damage to the pollen grains to allow for their positive identification.

Sediment Coring

With the assistance of Dr. Tim Kohler and Dr. John Jones from the Department of Anthropology at Washington State University, I extracted three sediment cores from a peat bog in Beef Pasture on August 8, 2005 in an effort to obtain a sediment profile that contained intact and undisturbed deposits that date from A.D. 600 to 1300 (Figures 5, 6, 9 and 10). Although the placement of each coring location was judgmental, we made efforts to avoid areas that exhibited potential signs of mechanical disturbance. My pilot project (Wright and Petersen 2005) revealed that the areas near Petersen's coring locale had been mechanically disturbed after 1973. To avoid these disturbed sediments, we cored in three areas between 20 and 40 m east and northeast of Petersen's (1988) coring locale (Figure 9). We measured core lengths in the field and recorded their locations with a hand-held GPS device (Table 2). We also collected a modern surface pollen sample at this time. Our sampling of the modern surface followed the "pinch" method (Adam and Mehringer 1975), and we randomly collected over 30 pinch samples within 80 m of the sampling locale. A reliable representation of the regional environment from a surface sample requires a minimum of eight pinches from around the vicinity of the sampling

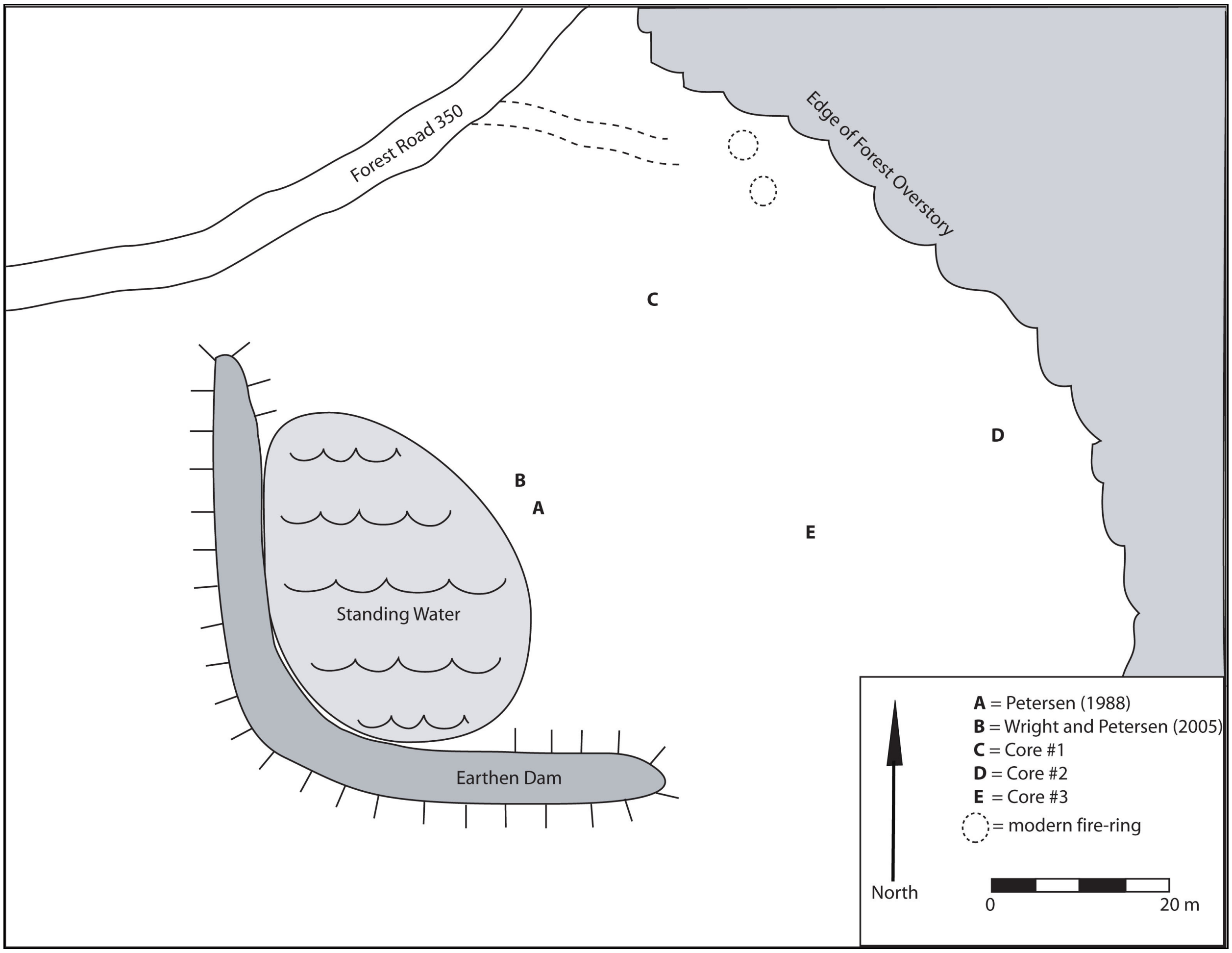

Figure 9. Locations of Beef Pasture pollen cores used and discussed in text.

locale (Adam and Mehringer 1975). We then placed these pinch samples in an air-tight bag and thoroughly mixed them by kneading to prevent over-representation of pollen types derived from any one of the samples.

We extracted the sediment cores using an Intek® 206 vibra-corer manufactured by Briggs & Stratton. We used a vibra-corer because it allows for the extraction of an entire core with only one coring drive, whereas other coring devices may require multiple drives to extract similar volumes of sediment. This eliminates potential problems derived from multiple drives, such as

Table 2. Coring Locations and Core Depths from Beef Pasture

Core No.	Northing	Easting	GPS Error Range	Core Length (m)
1	37° 28’ 30.9”	108° 9’ 18.8”	± 5 m	0.61
2	37° 28’ 29.9”	108° 9’ 15.9”	± 5 m	1.49
3	37° 28’ 28.6”	108° 9’ 16.8”	± 5 m	1.45
2003 core[a]	37° 28’ 28.6”	108° 9’ 19.3”	± 5 m	1.85

[a] core reported by Wright and Petersen (2005) that exhibited truncated deposits

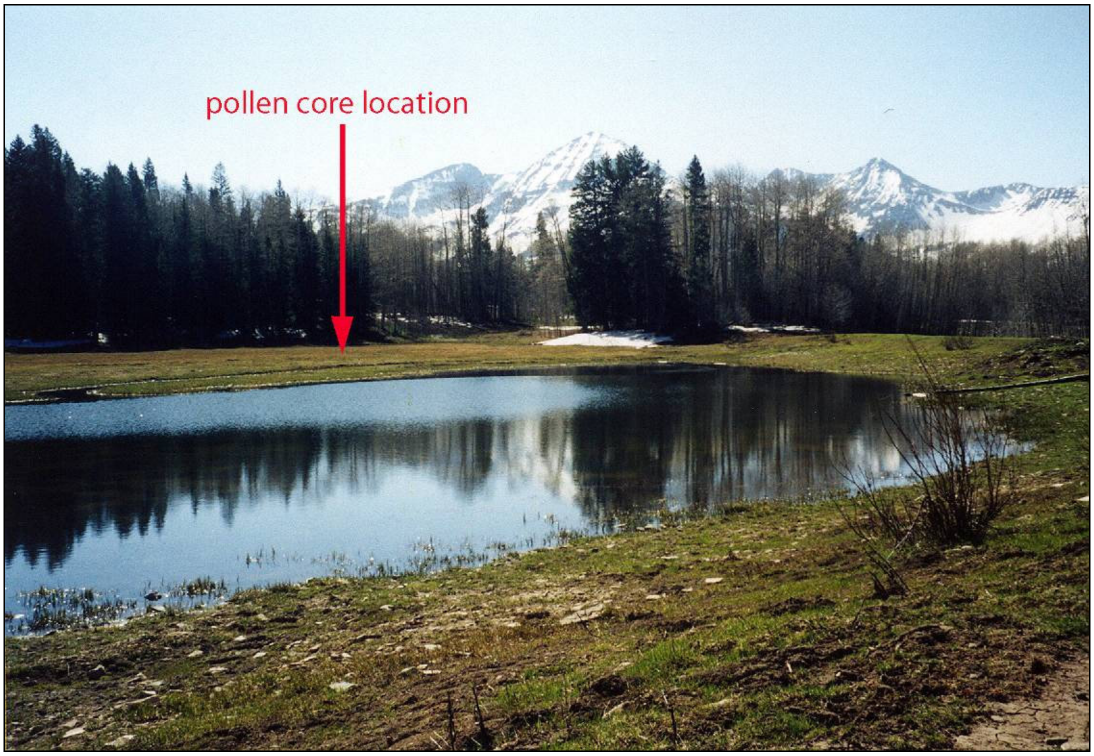

Figure 10. East-facing overview of Beef Pasture bog in June, 2003 with a man-made water-retention feature in foreground and the provenance of the pollen core used in this study (Core No. 3) (picture courtesy of Dr. Timothy Kohler).

the need to overlap and correlate coring drives and the compaction of sediment between drives. Sediment compaction resulting from coring with a vibra-corer is minimal and is restricted to the uppermost deposits. We used a three-inch diameter aluminum pipe, with a wall thickness of 1/20th of an inch, as the core tube. Once we extracted, capped, labeled and sealed the sediment cores with duct tape, Dr. John Jones transported them to Washington State University in Pullman, Washington where they remained in cold storage until I conducted ^{14}C and pollen sampling.

Pollen Sampling and Processing

I did not sample Beef Pasture sediment core No. 1 for either ^{14}C or pollen because bedrock was encountered less than 1 m below ground surface, suggesting a slow accumulation of sediments in that portion of the meadow. Beef Pasture sediment cores No. 2 and 3 contained deposits greater than 1.4 m below surface, and I submitted one ^{14}C sample from each of their midsections to the University of Arizona's Accelerator Mass Spectrometry Laboratory to verify that these cores contain sediments dating to the last 1,000 years. Once this was verified, I proceeded by processing Beef Pasture sediment core No. 3 for pollen samples at the Washington State University's Palynology and Paleoenvironmental Laboratory from August 22 to 28, 2005. Sediment cores No. 1 and 2 remain in cold storage at Washington State University for future research. I used electric shears to create two lengthwise incisions into the aluminum core tube, which exposed the sediments while minimizing disturbance of the core-body. I subsequently split the core lengthwise into two hemispherical bodies; one side for pollen sampling and the other for radiocarbon sampling (Figures 11 and 12). I conducted sediment descriptions, when wet, with the aid of *Munsell Soil Color Charts* (MacBeth Division of Kollmorgen Instruments Corporation 2000). I extracted pollen samples, each measuring approximately 1 x 2 x 3-cm, using a sterilized blade, and I cleaned this blade after each extraction in order to prevent cross-contamination of the samples. Prior to sample extraction, I removed the sediment that was in contact with the core tube with a sterile blade to prevent sample contamination from the downward movement of the core tube during coring.

Starting at 4 cm, just below the compacted surface of the core, I extracted 71 samples every other centimeter (Figures 11 and 12). I selected this sampling strategy for three reasons. First, such high-frequency pollen sampling permits a more accurate assessment of low-frequency paleoenvironmental change over short periods. Based on Petersen's sedimentation rates (1988: Figures 15 and 18, Table 6), approximately 10 to 20 cm of sediment accumulated at Beef Pasture every 100 years (0.049 – 0.100 cm/yr). Using this rate as an estimate for the current project, I expected each sample to reflect the pollen assemblage at Beef Pasture on the order of every 20 to 40 years. Second, sampling every other centimeter minimizes the potential for misrepresentation due to any post-depositional translocation of pollen while maintaining a high temporal resolution. The modern occurrence of *Typha latifolia* (cattail) at Beef Pasture, which has resulted from twentieth century cattle grazing as discussed in Chapter 2, demonstrates the effectiveness of this approach. While cattail is a prolific pollen producer, the minimal translocation of this pollen type is apparent in the Beef Pasture pollen profile (Figure 16). This suggests that the pollen assemblage of each sample is a reliable indicator of the vegetational assemblage around the sampling locale at any point in time, especially when one considers that the sediments at Beef Pasture have probably experienced more post-depositional disturbance during the twentieth century from recreation, logging, mechanical excavation, and cattle grazing than they did in earlier periods. Third, this sampling strategy provides the highest resolution stratigraphic palynological analysis from the Four Corners region to date.

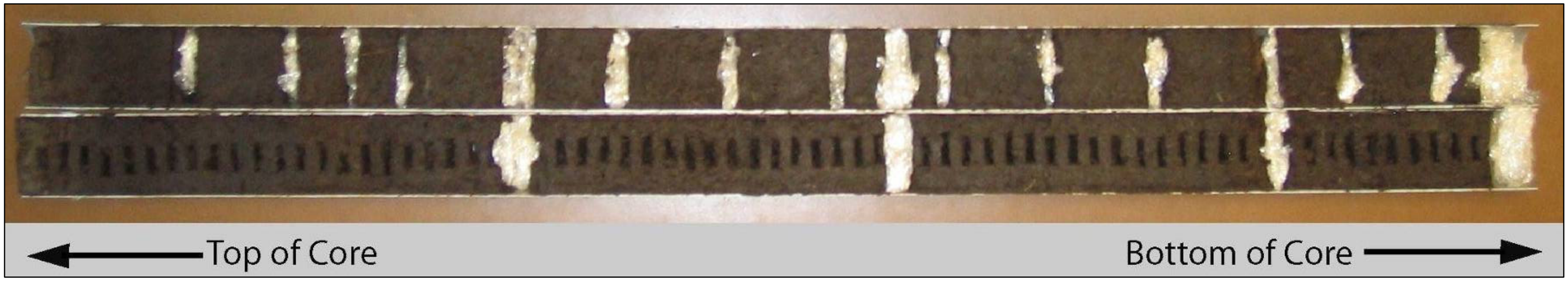

Figure 11. Post-sampling photograph of Core No. 3. Core is 1.45 m in length. Radiocarbon samples were extracted from the upper hemisphere, and pollen samples were extracted from the lower hemisphere. Plastic wrapping indicates locations of radiocarbon samples. Note that four of the radiocarbon samples also contained sediments from the pollen-sampling hemisphere.

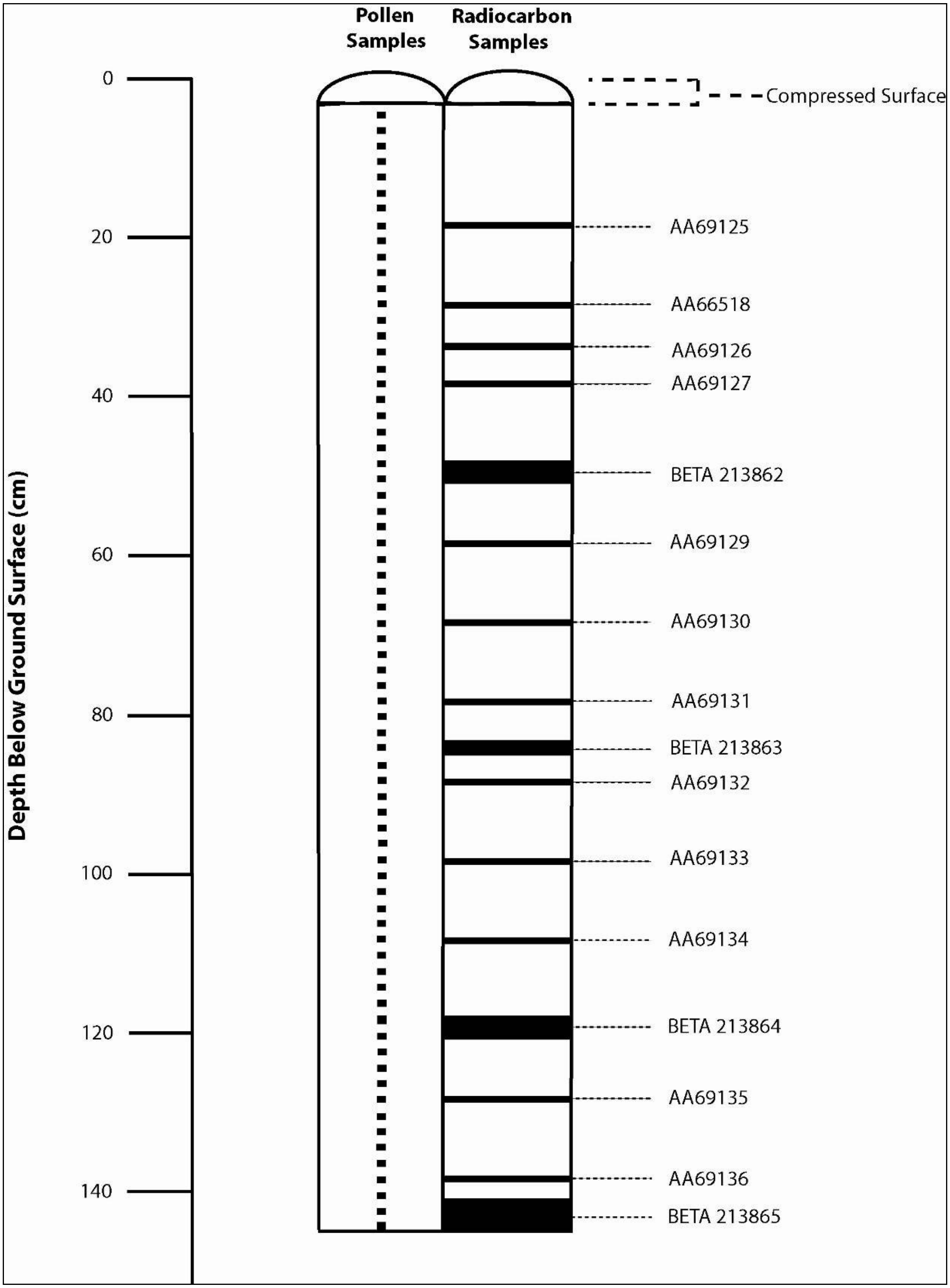

Figure 12. Diagram of Core No. 3 showing pollen and radiocarbon sampling locales by depth.

The methods used for the extraction of fossil pollen from core No. 3 followed closely those outlined by other palynologists (e.g., Faegri and Iversen 1989). I first quantified the Beef Pasture pollen samples to 3 cm^3 to standardize the sediment volume for all samples, which allows for comparison of fossil pollen concentrations and the influx rates of particular species between samples and zones, thus facilitating the identification of temporal fluctuations in the local vegetational assemblage. I then placed the samples in sterile beakers with five commercially prepared tablets of European *Lycopodium* sp. spores (Stockmarr 1971, 1973; Batch No. 124961), each containing 12,542 ± 416 spores, distilled water and several drops of hydrochloric acid (HCL). The addition of HCL allows for the removal of naturally occurring carbonates in the sediment as well as the carbonate bonding agent in the tablets of tracer spores. I chose *Lycopodium* sp. (club moss) spores as tracer spores because they are highly unlikely to be found in the actual fossil pollen assemblages from this region. Tracer spores are added to samples for two reasons. First, by adding a known quantity of exotic spores to a known quantity of sediment, fossil pollen concentration values and influx rates can be calculated by using ratio-estimate techniques (Beninghoff 1962). Second, in the event that no fossil pollen is observed in the sediment sample, the presence of *Lycopodium* sp. tracer spores verifies that processor error was not a factor in the pollen loss (Davis 1969a).

Following the addition of the tracer spores, distilled water and HCL, I disaggregated the samples on a magnetic mixer for approximately 90 minutes. Once disaggregated, I screened the samples through 150µ mesh screen in order to remove the larger, non-pollen organic fraction from the samples; I used 150µ mesh screen because it should allow the pollen of all known locally occurring plant species, even the large grains of *Pseudotsuga menziesii* (Douglas-fir) and *Abies lasiocarpa* (subalpine fir), with size ranges of 110 - 115µ and 100 - 125µ respectively

(Kapp et al. 2000), to be incorporated in the samples' pollen assemblages. Next, I rinsed and consolidated the samples through a series of spins in a centrifuge. I then added a solution of 50-percent hydrofluoric acid (HF), and the samples remained in this solution for 24 hours to allow for the complete removal of unwanted silicates. In order to remove undesirable humic acids, I then washed the residues in a solution of one-percent potassium hydroxide (KOH) and rinsed them until the samples attained a neutral pH.

After the samples attained a neutral pH following the acid treatments, I dehydrated them in glacial acetic acid (CH_3COOH). Once dehydrated, I subjected the samples to an acetolysis treatment (Erdtman 1960) consisting of 9 parts acetic anhydride (CH_3CO) to one part concentrated sulfuric acid (H_2SO_4). This step removes most unwanted organic materials, including cellulose, hemi-cellulose, lipids and proteins, and converts these materials to water-soluble humates. During this process, I placed the samples in a hot water bath for 10 minutes to aid in chemical digestion. Once completed, I made test slides of several samples to inspect the effectiveness of the acetolysis treatment. These test slides revealed that a considerable amount of unwanted organic matter remained in the samples, so the samples underwent an additional acetolysis treatment for 10 minutes. I then rinsed the samples in distilled water until a neutral pH was achieved. During acetolysis, it is possible for some fragile pollen grains to break down if the duration of treatment is too long; however, the presence of pollen from two species whose pollen often preserves poorly and breaks down easily during chemical treatment (*Populus* sp. [aspen] and *Pseudotsuga menziesii* [Douglas-fir]) suggests that the two 10-minute acetolysis treatments did not adversely affect any of the pollen grains. Following the acetolysis treatments, I next subjected the samples to a heavy density separation using zinc chloride (ZnCl) with a specific gravity of 2.00; here, I isolated the lighter organic fraction from the heavier residual minerals. I then dehydrated the organic residues in ethanol (ETOH) and transferred them to a glycerine medium for curation in glass vials.

Pollen Identification and Counting

I prepared permanent slides using glycerine as a mounting medium, and I made pollen identifications with the aid of a Nikon© compound stereomicroscope set at 400X magnification, from September, 2005 to January, 2006. My identifications were confirmed by using published keys and the Palynology and Paleoenvironmental Laboratory's extensive pollen reference collection. Since large grains may be more frequent toward the center of the slide and small grains more frequent along the edges, due to the inverse relationship between the weight of the cover slip and the migration of differentially sized grains (Brooks and Thomas 1967), I counted slides by means of vertical linear transects. When pollen concentrations were high and allowed for 500-grain counts prior to reaching the center of the slide, I counted additional grains until I reached the center of the slide to control for differential migration.

Many palynologists classify *Pinus* sp. pollen into either haploxylon (e.g., *Pinus edulis, Pinus flexilis*) or diploxylon (e.g., *Pinus ponderosa*) types based on the presence or absence of distal verrucae (Hansen and Cushing 1973; Jacobs 1985); however, the pine pollen identifications in this study consisted of differentiating between *Pinus edulis* and *Pinus ponderosa* based on overall pollen size and the ratio of bladder size to body size. Likewise, there was no effort to differentiate *Pinus flexilis* from the other local pine species. Considering that *Pinus flexilis* is not abundant in the vegetation of the La Plata Mountains, and that it has an elevational distribution similar to that of *Pinus ponderosa*, I believe that the inability to differentiate its pollen from the other pine species does not result in erroneous statistical measures or faulty interpretations. A similar limitation occurred with the identification of *Picea* *engelmannii* and *Picea pungens* (blue spruce) pollen. The latter also occurs in relatively low frequencies in the La Plata Mountains. Therefore, I did not distinguish between these two species even though they inhabit different vegetational zones, and I believe that statistical measures and interpretations are still reliable. I refer to both species here after as *Picea* sp. in figures, tables and text.

As for the distinction between *Pinus edulis* and *Pinus ponderosa*, Kapp et al. (2000:45) suggest that the pollen grains of the former are considerably smaller than those of the latter, which I also observed in this study. Likewise, they further suggest that the ability to differentiate pine pollen using the presence of distal verrucae, as suggested by Hansen and Cushing (1973) and Jacobs (1985), is less reliable for fossil pollen, which this study utilizes, than for modern reference samples (Kapp et al. 2000:45). My preliminary identification efforts in this study also suggested that the ratio of bladder-size to body-size for *Pinus edulis* is greater than that of *Pinus ponderosa*. However, I conducted no statistical measures to determine the reliability of this distinction. Regardless, I used the ratio of bladder-size to body-size in conjunction with overall grain-size to distinguish *Pinus edulis* from *Pinus ponderosa* pollen in this study. Provided that the pine pollen could be divided into two size classes, I classified these grains into groups of large pine and small pine, which I refer to here after as *Pinus ponderosa* and *Pinus edulis* respectively in figures, tables and text.

Broken grains of *Picea* sp., *Abies* sp. and *Pinus* sp. were frequent in the pollen assemblages and I counted them along with the other pollen types. If the body of the grain was present, then I counted it as a whole grain of that taxon, but bladders without bodies did not allow for reliable taxonomic identification. Thus, I classified bladders as either large (*Picea* sp. or *Abies* sp.) or small (*Pinus* sp.) in order to account for their presence in measures reliant on total pollen sums (pollen concentrations and influx estimates). I divided the counts of each bladder size by two, and I rounded fractions up, in order to more accurately represent the number of pollen grains that were broken; therefore, all single counts in these categories are reflective of the presence of two bladders. Since they could not be identified to a particular genus, I did not include these bladders in any of the taxon-specific analyses.

While minimum 200-grain counts are standard among most palynologists (Barkley 1934) and are thought to be fairly reflective of past vegetation and paleoenvironmental conditions and allow for reliable statistical analyses, I conducted larger grain counts here to account for rare and exotic species as well as to increase sample sizes for statistical analyses (Bowman 1931; Crabtree 1968; Maher 1972b). I counted each sample to a minimum of 500 grains, and when *Carex* sp. (sedge) grain totals exceeded 300 grains (samples 11 and 12, see Appendix A), I continued counts until at least 200 other grain-types were reached. Since pollen types confined to lowland aquatic and mire vegetation tend to be prolific pollen producers and are locally abundant, some researchers disregard their contribution to the pollen assemblage by excluding their counts from the total pollen sums (Birks and Gordon 1985:5-6); this ensures a reliable representation of other species indicative of regional vegetation. However, others (Cushing 1963; Birks 1973; Birks and Birks 1980) argue that the choice of which pollen types to include in pollen sums depends on the nature of the research question.

While arboreal pollen types provide measures of movement of the lower boundary of the spruce-fir forest, I argue here that sedge, a locally abundant aquatic taxon, is indicative of regional moisture regimes, primarily winter precipitation. Therefore, counts of *Carex* sp. pollen are essential to understanding the causal climatic conditions (temperature or moisture) that have influenced the movement of this boundary in the past and I include them in this study's pollen sums. Aside from *Carex* sp., *Juncus* sp., *Salix* sp. and *Typha* sp., there was no effort to identify the pollen grains of other locally occurring aquatic species, such as ferns (*Equisetum* sp., monolete and trilete spore-types), moss (*Brachythecium collinum*, *Aulacomnium* sp. and *Drepanocladus* sp.) and algae (*Botryococcus* sp. and *Pediastrum* sp.), because these species are rarely indicative of environmental conditions and are generally unidentifiable beyond the family-level; therefore, these plant types are unaccounted for in the pollen assemblages, pollen concentrations, and total pollen sums from Beef Pasture. My omission of these taxa should not greatly affect the total pollen sums and concentration values from Beef Pasture; Petersen's (1988:Figure 21) results indicate that they occur in extremely low frequencies at Beef Pasture between 0 and 160 cm below surface.

Once I finished all of the pollen counts, I calculated pollen concentration values and influx rates of each taxon for all samples. Hall (1981) and Bryant and Hall (1993) note that concentration values below 2,500 grains/cc of sediment may not reflect past conditions well, and usually record a differentially preserved assemblage. As a result, counts with low concentration values should be viewed with caution. The concentration values from Beef Pasture exceed this minimum considerably,however, which suggests that the samples are reliable indicators of past vegetation assemblages.

Sediment Dating

To verify that core No. 3 contained intact sediment deposits from the past 1,500 years, a preliminary ^{14}C sample from 28 to 29 cm below the surface was sent to the University of Arizona's Accelerator Mass Spectrometry (AMS) Laboratory for dating prior to pollen sampling. Four ^{14}C samples were subsequently processed by Beta Analytic using the traditional radiometric technique. To augment these five dates, and to double check the results of various labs, I personally processed an additional 11 ^{14}C samples with the assistance of Dr. George Burr from University of Arizona's Department of Physics and Atmospheric Sciences. We processed these samples at the University of Arizona's AMS Laboratory in March of 2006 through a generous internship provided by Dr. Burr.

All of the radiocarbon samples consisted of datable, bulk organic sediments dominated by woody sedge peat. The method of extraction for the radiocarbon samples from the core was similar to that of the pollen samples. I removed outer sediment in contact with the core tube, and I extracted the samples using a sterilized blade that I cleaned after each sample extraction. I removed any fresh rootlets with the aid of sterilized tweezers, and I wrapped the samples in aluminum foil and dried them in a drying oven at 105º C prior to other processing.

In the following chapter I present the results of the ^{14}C and pollen samples and discuss how I developed the various pollen measures (percentages, influx rates, ratios) that serve as proxies for climatic changes. In addition, I detail procedures used for developing a sedimentation rate, calculating pollen influx rates, and dividing the sediment core into biostratigraphic zones upon which statistical measures can be applied.

CHAPTER FIVE

RESULTS

In this chapter I present the results of the analyses discussed in Chapter 4, including sediment descriptions and the nature of pollen preservation I observed in the sample. Here, I discuss in detail the calibration results from the ^{14}C samples and the procedures I used for deriving a deposition rate and assigning age estimates to each sample. I also present the results of the pollen analysis, detail each of the measures I used on the pollen data, and discuss how I segregated the pollen samples into zones for statistical analyses.

Sediment Descriptions and Pollen Preservation

The sediment descriptions for core No. 3 are provided in Table 3. As with Petersen's samples (1988:Table 2), the majority of the core is composed of sedge detritus intermixed with a minimal quantity of conifer needles and twigs. The upper five centimeters of sediment is comprised of a silty clay *gyttja*, mostly likely the result of seasonal ponding due to the construction of a water-retaining wall in the 1940s. The fact that the majority of the core body is sedge peat indicates that *Carex* sp. has been locally present throughout the depositional history represented in the core. During pollen sampling and processing, I observed only minimal amounts of non-organic sediments, and these were comprised entirely of silts and clays, most likely aeolian in origin. West-to-east trending winds cutting across the Great Sage Plain have probably transported these sediments, along with the pollen of several genera (e.g., *Artemisia* sp.), into the higher reaches of the La Plata Mountains, which were deposited due to pollen rain, natural fallout or were filtered from the air by trees. Variations in the quantity of non-organic sediment deposition at Beef Pasture, however, may be related to differences in the type and density of overstory, which could aid in paleoenvironmental inferences, but it is equally

Table 3. Sediment Descriptions for Beef Pasture Core No. 3

Depth (cm)	Color[a]	Description
0 – 3.5	-	compression from coring, no sediment
3.5 – 6	dark gray (10YR 4/1)	silty clay *gyttja*
6 – 29.5	very dark brown (10YR 2/2)	sedge peat; slightly fibrous
29.5 – 37.5	dark reddish brown (5YR 2.5/2)	sedge peat; more fibrous than above
37.5 – 71	very dark grayish brown (10YR 3/2)	sedge peat; fibrous
71 - 117	very dark grayish brown (10YR 3/2)	sedge peat; less fibrous than above
117 – 125	dark reddish brown (5YR 3/3)	sedge peat; more fibrous than above
125 - 130	very dark brown (10YR 2/2)	sedge peat; fibrous
130 - 145	very dark brown (10YR 2/2)	sedge peat; less fibrous than above

[a] after *Munsell Soil Color Charts* (MacBeth Division of Kollmorgen Instruments Corporation 2000)

plausible that changes in wind patterns or erosional processes at lower elevations also contributed to such variation. Unmixing these processes would be a considerable endeavor and is beyond the scope of this analysis. Assuming that these sediments are a minimal fraction of the overall sediment composition and their depositional history is irrelevant to understanding local pollen deposition and preservation at Beef Pasture, I did not conduct any granulometric analyses.

While measures of sediment pH as well as organic and inorganic carbon are common in palynological analyses, I made no effort to acquire these data at Beef Pasture. Soil pH is a critical factor in pollen preservation since pollen is generally poorly preserved in sediments with a pH above 6.0 (Bryant et al. 1994; Dimbleby 1957). However, the pollen concentration values for this study (Appendix A) and previous analyses at Beef Pasture (Petersen 1988; Wright and Petersen 2005) along with the presence of fragile pollen types (e.g., *Typha* sp., *Populus* sp. and *Pseudotsuga* sp.) suggest that either pollen preservation at Beef Pasture is minimally affected by extreme pH values or that pH values are within a range that does not severely affect pollen preservation. A weight-loss-on-ignition protocol is standard procedure for estimating the amount of organic and inorganic carbon in sediments (Dean 1974; Galle and Runnels 1960; Konrad et al.

1970:204); such an analysis is useful for inferring paleoenvironmental conditions that influence the deposition rate of organic matter and carbonaceous sediments or influence the rate of organic decomposition. The sediments from Beef Pasture are fairly homogeneous texturally, being composed largely of sedge peat, and a weight-loss-on-ignition procedure did not seem warranted. Furthermore, the fact that the samples did not react with HCl during processing suggests that inorganic carbon was virtually nonexistent within the sediments.

Periodic episodes of aeration of the sediments could also result in corrosion of pollen grains by fungal and bacterial digestion or degradation by chemical oxidization (Moore et al. 1991:169-170), but the morphology of the identified grains suggests that such activity was minimal at Beef Pasture. Given that Beef Pasture is an alpine fen characterized by year-round saturation of the sediments, aeration in the past, if it occurred, was probably infrequent. It is possible that anaerobic bacteria could cause pollen corrosion under saturated conditions (Clymo 1965), however, corrosion rates are very reduced in such circumstances. In sum, soil chemistry and microbial attack do not appear to have adversely affected the pollen preservation at Beef Pasture, at least of the taxa pertinent to this analysis. I assume, therefore, that the pollen assemblage is a fairly accurate record of the actual pollen deposited at Beef Pasture, and by extrapolation, provides a reliable proxy for past environmental conditions.

^{14}C Dates and Sedimentation Rates

The results of the 16 radiocarbon assays used in this study are presented in Table 4. I calibrated the uncorrected dates with CALIB® Rev. 5.0.1 (Figure 13; Table 4) (Stuiver and Reimer 1993; Stuiver et al. 2005). As Figure 13 and Table 4 show, for some samples there is more than one possibility for the correct calibrated calendrical date-range, and each range is equally probable of being correct at both the 1-σ (68.3 percent) and 2-σ (95.5 percent)

Table 4. Radiocarbon Samples and Results

Depth (cm)	Laboratory[a]	Technique[b]	Lab No.	Uncorrected Date (BP) at 1σ	Calibrated Dates (A.D./B.C.) at 1σ[c, d]	Calibrated Dates (A.D./B.C.) at 2σ[c]
18 - 19	UA	AMS	AA69125	94 ± 37	1893 ± 26 1860 ± 00 1846 ± 06 1826 ± 13 **1711 ± 16**	1870 ± 68 1758 ± 05 1710 ± 29
28 - 29	UA	AMS	AA66518	422 ± 35	1460 ± 25	1605 ± 15 1579 ± 02 1470 ± 50
33 - 34	UA	AMS	AA69126	426 ± 37	1459 ± 26	1606 ± 15 1579 ± 03 1469 ± 52
38 - 39	UA	AMS	AA69127	496 ± 36	1426 ± 14	1423 ± 29 1335 ± 08
48 - 51	BETA	TR	213862	780 ± 50	1252 ± 34	1226 ± 67
58 - 59	UA	AMS	AA68129	846 ± 38	1250 ± 02 1237 ± 04 **1194 ± 34**	1209 ± 59 1131 ± 08 1067 ± 19
68 - 69	UA	AMS	AA69130	914 ± 34	1154 ± 08 1131 ± 13 **1073 ± 30**	1202 ± 05 1111 ± 80
78 - 79	UA	AMS	AA69131	1079 ± 37	1009 ± 05 974 ± 25 **909 ± 10**	956 ± 63
83 - 85	BETA	TR	213863	1190 ± 90	940 ± 22 **833 ± 66** 729 ± 15	1009 ± 03 831 ± 165
88 - 89	UA	AMS	AA69132	1342 ± 37	**757 ± 05** 669 ± 21	754 ± 18 683 ± 46
98 - 99	UA	AMS	AA69133	1567 ± 37	**522 ± 17** 464 ± 30	493 ± 79
108 - 109	UA	AMS	AA69134	1743 ± 37	292 ± 49	309 ± 96 183 ± 04
118 - 121	BETA	TR	213864	1740 ± 80	311 ± 96	523 ± 07 501 ± 12 261 ± 177
128 - 129	UA	AMS	AA69135	1914 ± 40	**91 ± 39** 34 ± 04	109 ± 106
138 - 139	UA	AMS	AA69136	1929 ± 39	111 ± 14 **71 ± 22** 34 ± 07	202 ± 07 162 ± 07 67 ± 74 -23 ± 16
141 - 144.5	BETA	TR	213865	2150 ± 60	**-157 ± 57** -223 ± 07 -322 ± 31	-208 ± 161

[a] UA = University of Arizona AMS Laboratory, Tucson. BETA = Beta Analytic, Inc, Miami, FL.

[b] TR = traditional radiometric with extended counting. AMS = radiometric via accelerator mass spectrometry.

[c] calibrated with CALIB® Rev. 5.0.1 (Stuiver and Reimer 1993; Stuiver et al. 2005)

[d] bold indicates calibrated dates selected for this study based on a linear regression of samples with only one option at 1σ. The midpoints of the dates in bold fell closest the point estimated by the regression equation.

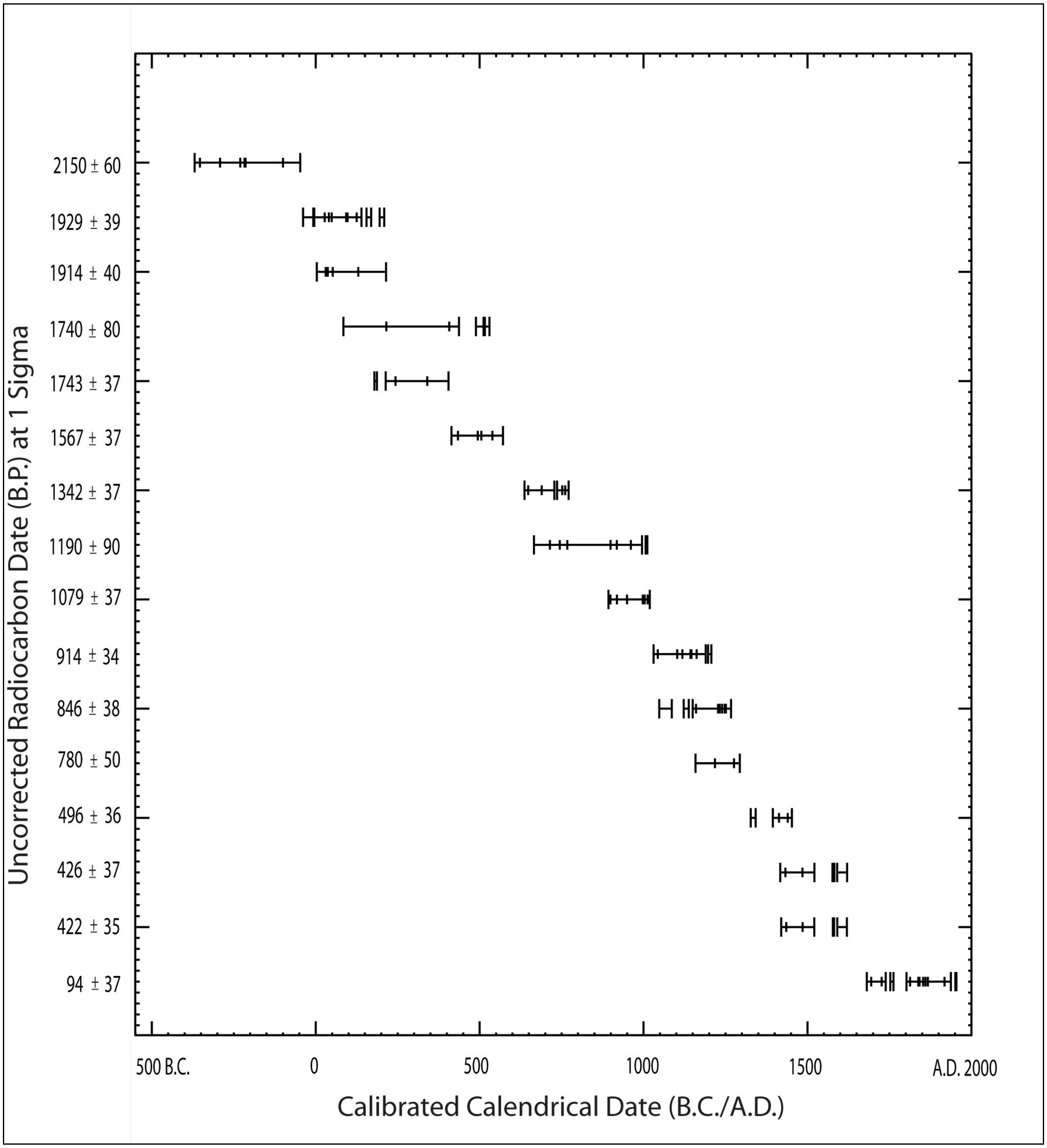

Figure 13. Calibration plot of ^{14}C dates used in this analysis, modified from output provided by CALIB® Rev. 5.0.1 (Stuiver et al. 2005).

significance levels. To obtain the desired high-resolution of chronological control to place the narrowly-spaced pollen samples into archaeologically-appropriate temporal context (Butzer 1982; Dincauze 2000), I used a two-step linear regression procedure to identify the most likely date-range from the samples with multiple date-ranges at the 1-σ level, with depth-below-surface (cm) as the independent variable and calibrated date as the dependent variable. In the first pass I used only those samples with one calibrated date-range at the 1-σ level along with the date for the modern ground surface ($n = 7$) to predict the most likely calibrated date-ranges of the other samples ($n = 16$). In essence, I elected to use the date-ranges that fell closest to the date predicted by the regression equation (in bold in Table 4) for use in assigning estimated dates to each sample and for calculating sedimentation rates. Then I used the other regression techniques below with all 16 samples.

I applied Maher's (1972a:540-544) method for calculating the deposition rate at Beef Pasture with the 16 calibrated calendrical dates and 1 modern date. This method involves regressing the midpoints of the calibrated date-ranges onto the samples' depth-below-surface. Since deposition rates of a locality are likely to be inconsistent through time, strictly linear relationships between depth and age should not necessarily be expected. With this in mind, I applied several linear and curvilinear regressions to the data to find the 'best-fit' equation, which I could then use as the equation for calculating the sedimentation rates. I explored the utility of quadratic, cubic, quartic, and weighted-least-squares regressions of calibrated calendrical dates on depths. The weighted-least-squares (WLS) regression accounted for the most variation in the samples, and I decided to use it for calculating the deposition rate at Beef Pasture (year A.D. = 2000.18 – 14.32*cm-below-surface, $r = .997$, $p < .0001$) (Figure 14). WLS regression is an effective method for dealing with situations when the data points for the independent variable

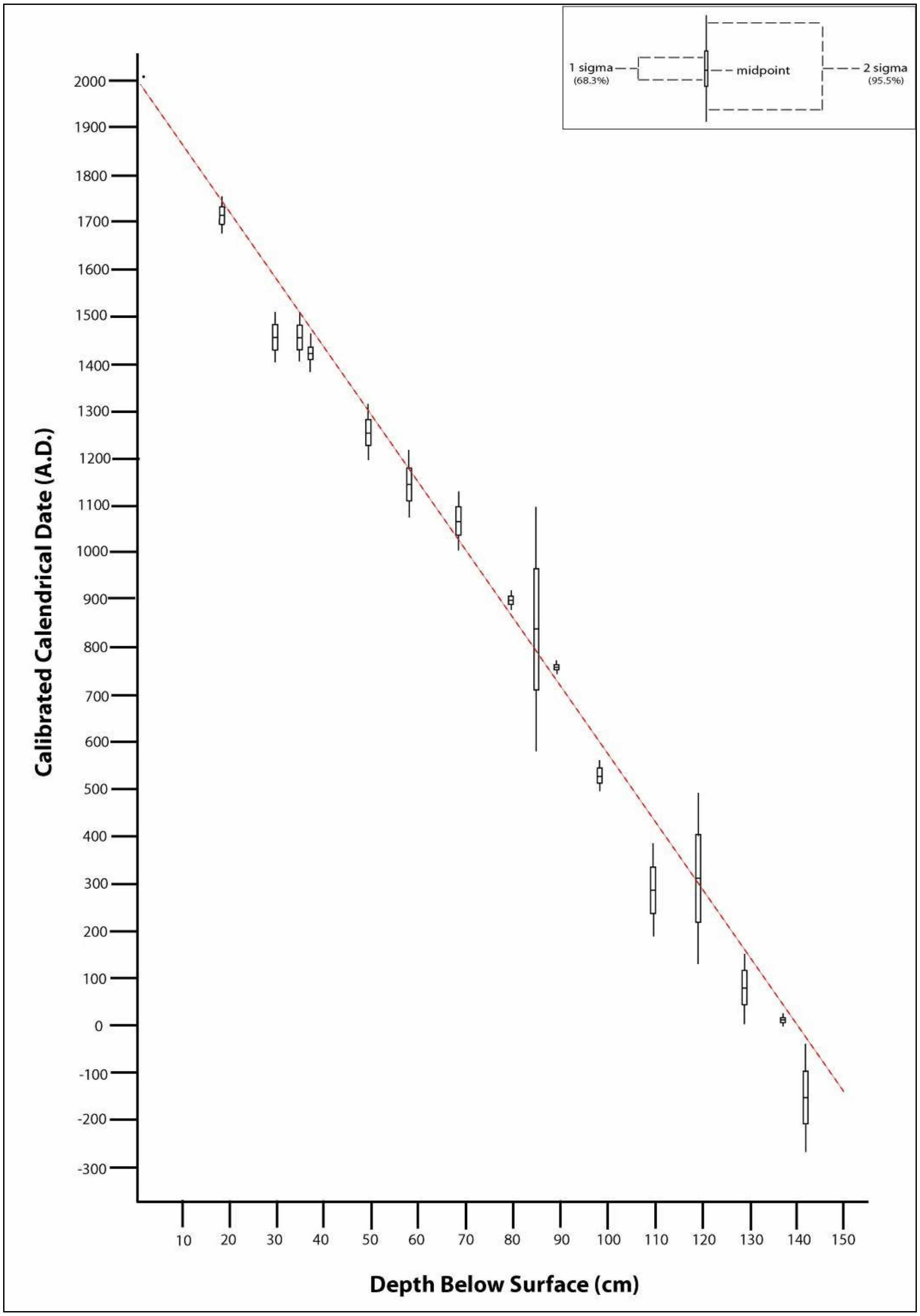

Figure 14. Weighted-least-squares regression of calibrated ^{14}C dates on depth used to derive age estimates for each pollen sample and to calculate a deposition rate (year A.D. = 2000.18 – 14.32*cm-below-surface, $r = .997$, $p < .0001$).

are of varying quality, such as calibrated ^{14}C dates with different standard deviations. Essentially, WLS regression adds weights to each data value for the independent variable that is inversely proportional to the variance of each data point; in other words, those values with low variances are more important in determining the location of the regression line (see Abdi 2003).

Although I did not assume a linear relationship between depth and calibrated calendrical date, the WLS regression in fact provided the best fit, suggesting that sediment deposition at Beef Pasture over the past 2,100 years has been fairly uniform through time. Although this method homogenizes the deposition rates of smaller scales that are likely to be highly variable (e.g., season-to-season, year-to-year), a multi-decadal deposition rate is compatible with the scales of the archaeological record, the pollen sample intervals used in this analysis and the low-frequency climatic fluctuations that I wish to identify. Therefore, I used the formula of the least-squares regression to estimate the age of each pollen sample (Appendix A) and to calculate a deposition rate. The sedimentation rates at Beef Pasture allow me to estimate the age of each pollen sample as well as to estimate pollen influx rate-per-year instead of per-volume for each sample.

To calculate the deposition rate at Beef Pasture, I subtracted the estimated date of the bottom-most sample (47 B.C. at 144 cm-below-surface) from the estimated date of the surface (A.D. 2000) and divided it by the number of centimeters between these two points (144 cm). Given the linear deposition rates from Figure 14, this allows me to estimate the deposition rate at 0.07 cm/year, or 7 cm/century, for the entire length of the core. This rate is very similar to the average deposition rate of 0.078 cm/year that Petersen (1988:Table 6) calculated for the past 2,485 years at Beef Pasture. Petersen, however, identified three different deposition rates over the past 2,485 years, ranging from 0.06 cm/year to 0.10 cm/year, but his calculations were based on only three ^{14}C dates and were calculated by dividing the difference in the midpoints of the three calibrated ^{14}C dates for each sample by the amount of sediment deposition between them. This method is different than that employed here, where I divided the differences in the estimated dates that I derived from the weighted-least-squares regression analysis by the amount of sediment deposition between them. Although our methods differ slightly the results are quite compatible, and an inspection of Petersen's (1988:Figure 25) deposition-rate curve for the past 2,800 years suggests that he also developed a fairly linear, and thus relatively constant, deposition rate for Beef Pasture during the late Holocene. Given that Petersen cored at another locality within Beef Pasture, minor differences between our calculations should be expected. I believe that the constant deposition rate of 0.07 cm/year that I calculated is an accurate estimate of the multi-decadal deposition rate that occurred at Beef Pasture over the past 2,100 years, and I used this estimate to derive pollen influx rates for each sample.

Total Pollen Counts and Pollen Concentrations

Pollen counting resulted in the identification of 48 different pollen types (excluding the spores of algae, moss and ferns) and these include 12 arboreal, 26 non-arboreal, 3 aquatic and 7 unknown types (Table 4); total counts for each pollen type of each sample are presented in Appendix A. Pollen concentration values are critical for stratigraphic palynological inference because they provide a constant ratio of total pollen influx throughout the profile; they also facilitate the calculation of pollen influx rates of a particular taxon. As an estimate of the total pollen influx for a given volume of sediment, differences in pollen concentrations between samples can be attributed to variable rates of sediment deposition, changes in pollen production or deposition, or processor error. Given that processing methods were consistent across all samples, the latter is unlikely for this study. Following Davis (1969a, 1969b) and Kirkland (1967), pollen concentration values for each sample were derived from the formula:

$$\text{Pollen concentration of sample } X = (N_1G) \div (N_2V)$$

where N_1 = number of *Lycopodium* sp. spores added to the sample (here, 62,710 spores)

N_2 = number of *Lycopodium* sp. spores counted

G = number of pollen grains counted

V = volume of sediment in the sample (here, 3cc)

Pollen Zonation

Pollen data, including frequencies, influx rates and ratios, should be expected to vary considerably between samples, so pollen zones are often employed to overcome such noise and to discover relatively homogeneous, adjacent temporal segments of paleoenvironmental relevance (e.g., Mehringer et al. 1977:358-362; Petersen 1988:44). Further, grouping pollen data into zones allows the identification of significant changes through statistical measures. Although zonal distinctions in palynology are often referred to as 'pollen zones', they are in fact zones of sediment, or biostratigraphical zones (Hedberg 1972:222-227), that are distinguished from one another by the relative frequencies of different pollen types, pollen concentrations, charcoal, etc. (Birks and Gordon 1985). As Birks and Gordon (1985:48) state, there is no commonly accepted method of pollen zonation; analysts employ both statistical and inferential techniques to distinguish them. In this study, I identified pollen zones through quantitative measures to avert any preconceptions or assumptions about the sedimentology, past climatic, past vegetational or temporal aspects that relate to pollen deposition at Beef Pasture (Gordon 1981:5; Janssen 1980); thus, this approach is inductive.

There are numerous clustering methods useful for grouping data into manageable

Table 5. Pollen Types Identified in Beef Pasture Sediments Excluding Algae, Moss and Ferns

Pollen Type	Scientific Name	Common Family Name	Common Name	Habitat Class
Abies	*Abies lasiocarpa*	pine	subalpine fir	arboreal
Alnus	Betulaceae *Alnus icana*	birch	alder	arboreal
Apiaceae	Apiaceae	parsley	various	non-arboreal
Artemisia	*Artemisia* sp.	sunflower	sage varieties	non-arboreal
Asteraceae, High-spine	Asteraceae	sunflower	various	non-arboreal
Asteraceae, Low-spine	Asteraceae	Ragweed/goldenrod	various	non-arboreal
Betula	*Betula fontinalis*	birch	water birch	arboreal
Carex	*Carex* sp.	sedge	various	aquatic
Celtis	*Celtis reticulata*	elm	hackberry	arboreal
Cirsium	*Cirsium* sp.	sunflower	thistle	non-arboreal
Cheno/Am	Chenopodiaceae/*Amaranthus*	goosefoot/pigweed	various	non-arboreal
Ephedra torreyana	*Ephedra torreyana*	ephedra	Mexican tea	non-arboreal
Ephedra viridis	*Ephedra viridis*	ephedra	Mormon tea	non-arboreal
Fabaceae	Fabaceae	pea	various	non-arboreal
Fragaria	*Fragaria* sp.	rose	wild strawberry	non-arboreal
Geraniaceae	*Geranium* sp.	geranium	wild geranium	non-arboreal
Juncus	*Juncus* sp.	rush	various	aquatic
Juniperus	*Juniperus* sp.	juniper	various	arboreal
Lamiaceae	Lamiaceae	mint	various	non-arboreal
Liguliflorae	*Liguliflorae* sp.	lettuce	various	non-arboreal
Lythraceae	*Lythrum* sp.	loosestrife	various	non-arboreal
Onagraceae	Onagraceae	evening primrose	various	non-arboreal
Opuntia	*Opuntia* sp.	cactus	prickly pear cactus	non-arboreal
Parthenocissus	*Parthenocissus* sp.	grape	various	non-arboreal
Pinus edulis	*Pinus edulis*	pine	pinyon pine	arboreal
Pinus ponderosa	*Pinus ponderosa*	pine	ponderosa pine	arboreal
Picea engelmannii	*Picea engelmannii*	pine	Engelmann spruce	arboreal
Poaceae	Poaceae	grass	various	non-arboreal
Polemoniaceae	Polemoniaceae	phlox	various	non-arboreal
Polygala	*Polygala* sp.	milkwort	various	non-arboreal
Populus	*Populus tremuloides*	willow	quaking aspen	arboreal
Pseudotsuga	*Pseudotsuga menziesii*	pine	Douglas-fir	arboreal
Quercus	*Quercus gambelii*	beech	Gambel oak	arboreal
Ranunculaceae	Ranunculaceae	buttercup	various	non-arboreal
Rosaceae	Rosaceae	rose	various	non-arboreal
Rubus	*Rubus idaeus*	rose	wild raspberry	non-arboreal
Salix	*Salix brachycarpa*	willow	barren ground willow	arboreal
Sarcobatus	*Sarcobatus* sp.	goosefoot	greasewood	non-arboreal
Thalictrum	*Thalictrum fendleri*	meadowrue	Fendler's meadowrue	non-arboreal
Typha	*Typha latifolia*	cattail	common cattail	aquatic
Verbenaceae	Verbenaceae	verbane	various	non-arboreal
Unknown Types	unknown	unknown	unknown	unknown

units and for elucidating similarities and differences between such groups. Here, I used a stratigraphically constrained incremental sum-of-squares (CONISS) cluster analysis, provided by Tilia® Version 2.0 software (Grimm 1987), on the proportion of each taxon in the pollen sum (percentage) of each sample. Unlike a normal sum-of-squares analysis, CONISS employs a sequential constraint by which samples become linked through the incremental method (Ward's method) only if they are stratigraphically adjacent. This clustering method attempts to identify 'homogeneous' clusters (Shennan 1997:240) by relying on the error sum-of-squares as a measure of distance. Such clustering methods are common in paleoecological studies because they facilitate the identification of significant changes through time. At Beef Pasture and Twin Lakes, Colorado, Petersen (1988:34-35, Figures 16 and 17) used OPTAGG 1, a modified version of Orloci's (1976:194) cluster analysis program for plant communities that is also stratigraphically constrained.

A limitation of stratigraphically constrained cluster analyses is that they do not provide a means to identify similarities between non-sequential environmental regimes. For example, if the pollen profiles of two zones appear similar but are stratigraphically discontinuous, this clustering procedure does not identify how similar (or different) they are. To overcome this limitation, however, data can be displayed in a manner conducive for identifying similarities and differences between zones. Here, I display proxy data from the indicator taxa for each sample and zone in the form of line graphs, barcharts, and box plots (discussed later). These facilitate the identification of similarities in each climatic variable and overall climatic regimes through time regardless of their sequential associations.

To ensure that the cluster analysis differentiated the samples into pollen zones that are meaningful for paleoenvironmental inference, I ran the CONISS program on two different sets of variables and compared the results to one another (Figure 15). The first analysis consisted of the proportions of each identified pollen type (n = 48) while omitting the unidentifiable Pinaceae pollen bladders from the variables and from the total pollen sum. Considering that the entire pollen spectra contains a significant amount of noise, or the potential effects of variables irrelevant to the current study or with little inferential potential, I conducted a second cluster analysis only on the indicator taxa pertinent to inferences of climatic change: spruce, pinyon pine, ponderosa pine, sedge and Cheno/Am. As Figure 15 demonstrates, the results of the two analyses are nearly identical in the dendrogram they generate although, as expected, they differ in the values of their error sum-of-squares measures. The fact that the cluster analyses grouped the samples in a similar manner suggests that the five indicator taxa (spruce, pinyon, ponderosa, sedge and Cheno/Am) are the variables that account for the majority of variability between the samples.

Given the similarity between the two cluster analyses, I partitioned the 72 samples into 11 pollen zones (Figure 15, Table 6) and a surface specimen. I selected the 11-zone solution from the cluster analysis for two reasons. First, this solution grants each zone an adequate number of pollen samples for statistical comparisons while also providing zones with fairly short temporal ranges. Second, I compared the visual trends in the pollen measures of each indicator taxa (Appendix B) to various levels of grouping in the cluster analysis. This comparison revealed that the major trends in each climatic variable are best identified by segregating the core into zones with combined error sum-of-squares less than 0.75. Thus, I identified these zones through a combination of objective (error sum-of-squares) and subjective (visual trends) methods that I argue best reflect the paleoclimatic variables I wish to elucidate.

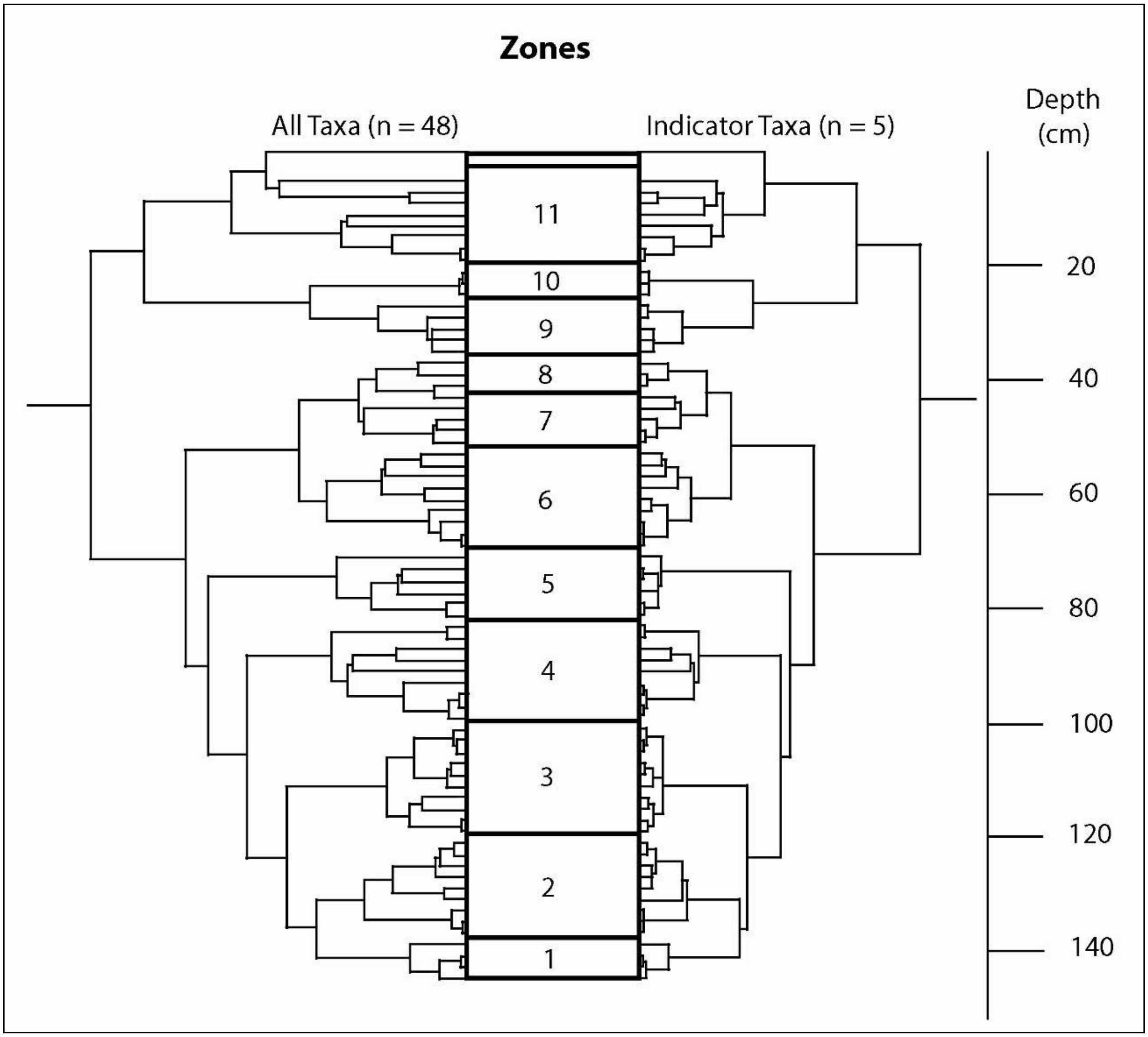

Figure 15. Stratigraphically constrained cluster analysis results. Dendrogram on left consists of all 48 taxa while the dendrogram on right consists of only the indicator taxa used in this study. Note that, with the exception of pollen sample #21 at 42.5 cm below surface, the samples were isolated to the same clusters in both analyses, suggesting that the indicator taxa account for the majority of the variation in the pollen assemblages.

Table 6. Pollen Zones of Beef Pasture Core No. 3

Zone	Depth Below Surface (cm)	Estimated Date Range (cal. B.C./A.D.)	Number of Samples	Mean Pollen Concentration Value
11	4 - 19	A.D. 1721 - 1940	8	62,266
10	20 - 25	A.D. 1636 - 1720	3	53,360
9	26 - 35	A.D. 1491 - 1635	5	59,805
8	36 - 41	A.D. 1406 - 1490	3	33,753
7	42 - 51	A.D. 1266 - 1405	5	36,450
6	52 - 69	A.D. 1006 - 1265	9	29,212
5	70 - 81	A.D. 836 - 1005	6	47,296
4	82 - 99	A.D. 576 - 835	9	62,931
3	100 - 119	A.D. 291 - 575	10	34,887
2	120 - 137	A.D. 36 - 290	9	26,005
1	138 - 145	100 B.C. - A.D. 35	4	34,352

Pollen Percentages

Figure 16 presents the pollen frequencies, or the percentage of the total pollen sum, for all arboreal taxa, including unidentifiable Pinaceae bladders, the 15 most frequent non-arboreal taxa and the two most frequent aquatic taxa. Inspection of Figure 16 suggests that the pollen frequencies of spruce, pinyon, ponderosa, sedge and Cheno/Am, the primary paleoclimatic indicator species used in this study, are highly variable through the profile, and it is believed that this variation is related to climatic oscillations that influence the production and deposition of these pollen grains. Along with the frequency variability, Figure 16 demonstrates that a considerable amount of frequency noise is created by the inclusion of rare taxa and species that are insensitive to climatic change. Therefore, to ease inspection, the frequencies of each indicator taxon have been visually isolated in Appendix B. Likewise, considering that extreme variation between samples is expected, and does occur in the Beef Pasture pollen assemblage, low-frequency climatic data can be better expressed by the frequency-mean of pollen zones. Table 6 lists the mean pollen frequency of each indicator taxa for each zone, and the spreads for each zone are presented in Appendix C.

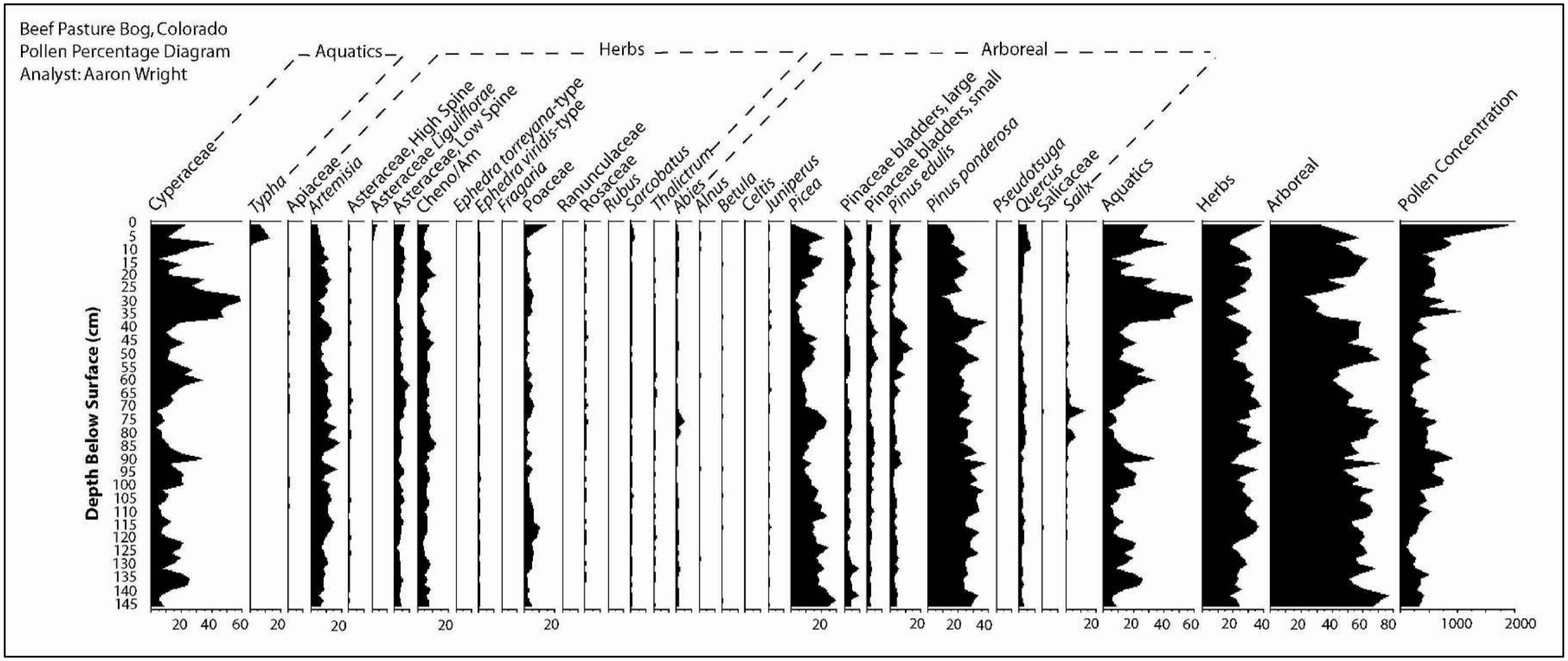

Figure 16. Pollen percentage diagram of most common pollen types from Beef Pasture Core No. 3 by depth.

Table 7. Mean Pollen Percentages of Indicator Taxa for Each Pollen Zone

Zone	Estimated Date Range (cal. B.C./A.D.)	Spruce	Ponderosa Pine	Sedge	Cheno/Am	Pinyon Pine
11	A.D. 1721 - 1940	15.5	20.6	17.4	6.8	4.2
10	A.D. 1636 - 1720	7.7	19.2	31.0	6.6	3.2
9	A.D. 1491 - 1635	4.7	15.4	51.5	3.0	2.2
8	A.D. 1406 - 1490	7.1	31.7	14.3	5.8	9.2
7	A.D. 1266 - 1405	14.6	25.2	14.1	7.3	9.6
6	A.D. 1006 - 1265	9.3	23.9	19.4	6.9	4.4
5	A.D. 836 - 1005	19.2	24.8	6.0	7.6	3.0
4	A.D. 576 - 835	10.6	28.3	18.3	7.5	4.0
3	A.D. 291 - 575	17.0	30.2	8.3	5.9	3.5
2	A.D. 36 - 290	18.8	25.9	18.1	5.4	3.9
1	100 B.C. - A.D. 35	25.5	28.4	8.2	6.9	4.2

Ratios of Indicator Taxa

Considering that the pollen frequencies of indicator taxa can fluctuate in response to changes in the proportion of pollen of non-indicator taxa, and are thus potentially misleading for climatic reconstructions, ratios between indicator taxa can demonstrate fluctuations that are poorly expressed in frequency diagrams. In fact, Maher (1961, 1963, 1972a) popularized this approach by analyzing the ratio of *Picea* sp.-to-*Pinus* sp. pollen to interpret percentage diagrams from Colorado. Provided that these ratios are reflections of the actual counts of pollen grains, chi-square tests of significance (see Mosimann 1965) could be applied between samples. Significant differences between zones, however, should be a more realistic measure of past low-frequency climatic changes; thus student's *t*-tests are applied to the spread of the ponderosa-to-spruce pollen ratios in each zone to demonstrate statistically significant differences.

In this study, I use the ratio of ponderosa-to-spruce pollen to infer changes in the density and proximity of spruce to the sampling locale. This measure is believed to reflect the duration of snowpack at Beef Pasture, which is in turn determined by winter precipitation and annual temperatures. While Petersen (1988) used the ratio of spruce-to-pine (both pinyon and ponderosa) at Beef Pasture to infer changes in the elevation of the lower subalpine forest boundary, this study omits pinyon pine from this ratio. Petersen (1988) used the spruce-to-pine ratio to correlate ratios at Beef Pasture with those of Twin Lakes, Colorado. However, the spruce-to-pine ratio is more apt for analyzing movement of the upper boundary of the subalpine forest (as at Twin Lakes) because the inclusion of pinyon allows for a more robust measure of extra-local pollen influx. Since the lower subalpine forest boundary at Beef Pasture is marked by a distinction between spruce and ponderosa trees, and not the presence/absence of a spruce-dominated forest overstory noted for the upper subalpine forest boundary, this study utilizes the pollen ratio of ponderosa-to-spruce to provide a more locally appropriate measure.

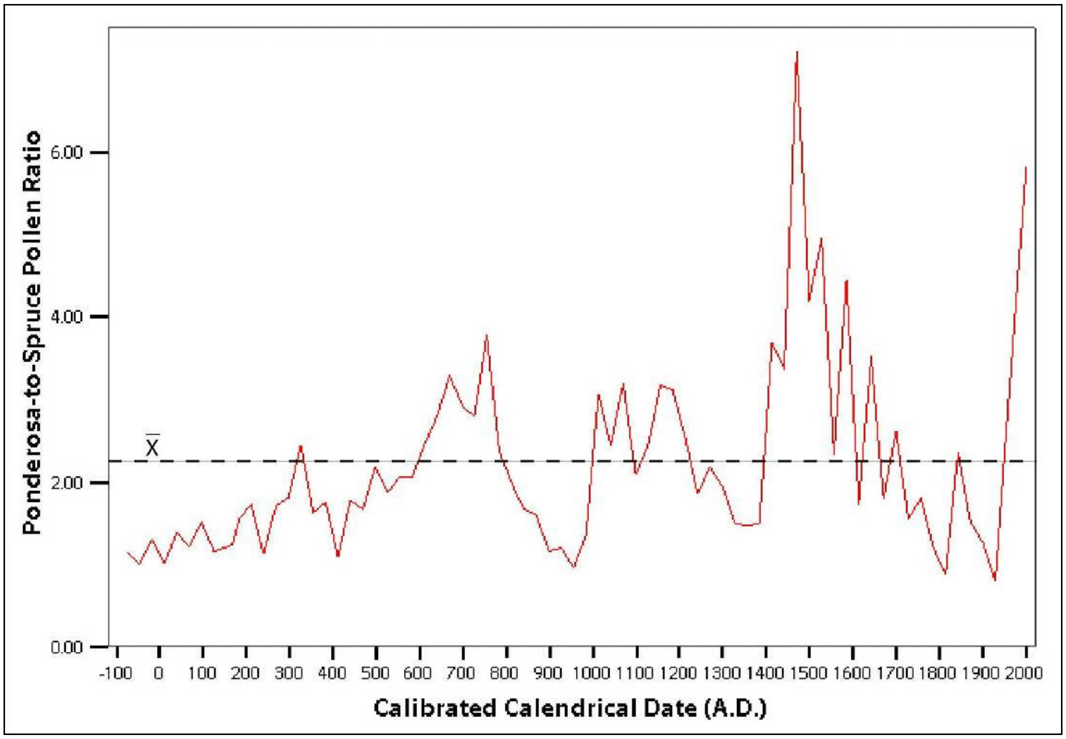

Figure 17. Ponderosa pine-to-spruce pollen ratios for all samples plotted by the sample's estimated calendrical date around the mean ratio (2.19) for the entire assemblage. Increases in this ratio imply an increase in annual temperature, winter precipitation, or both.

Figure 17 presents the ponderosa-to-spruce pollen ratio for each sample and Appendix C displays the spread of this ratio for each zone.

To unmix the climatic causes (winter precipitation or temperature) for the movement of the lower subalpine forest boundary, this study uses the ratio of sedge-to-Cheno/Am pollen for the reasons presented in Chapter 3. Based on the climatic expectations for the successful establishment and propagation of these two taxa, I expect that increased frequencies of sedge pollen will correlate with decreased frequencies of Cheno/Am pollen, and vice versa. Since this palynological relationship has yet to be tested beyond inferences based on frequency changes through time (e.g., Vierling 1998), Beef Pasture provides an opportunity to examine whether this relationship exists between the presence of either sedge or Cheno/Am species around the fen. In fact, a regression of sedge pollen-frequencies onto the logarithm of Cheno/Am pollen-frequencies for all samples from Beef Pasture (Figure 18) demonstrates that a relationship of this sort existed in the past ($r = .572$; $p < .0005$, $y = - 0.3863 - 0.201*\ln(x)$), where the frequency of sedge pollen is significantly negatively correlated with the frequency of Cheno/Am pollen. The correlation coefficient increases when the frequencies are averaged by zone to omit extreme sample-to-sample variation ($r = .790$; $p < .004$, $y = - 0.8819 - 0.384*\ln(x)$). Provided that a negative relationship between the presence of sedge and Cheno/Am pollen-types probably existed in the past, the sedge-to-Cheno/Am pollen ratio serves as a measure of changing winter precipitation in the past. Therefore, a distinction between winter precipitation and temperature as the impetus for the movement of the lower elevational boundary of the subalpine forest is possible when this ratio is compared with the ponderosa-to-spruce ratio. Figure 19 presents the sedge-to-Cheno/Am ratios for each sample, and Appendix C displays the spread of this ratio for each zone. Table 8 lists the mean pollen ratios for each zone.

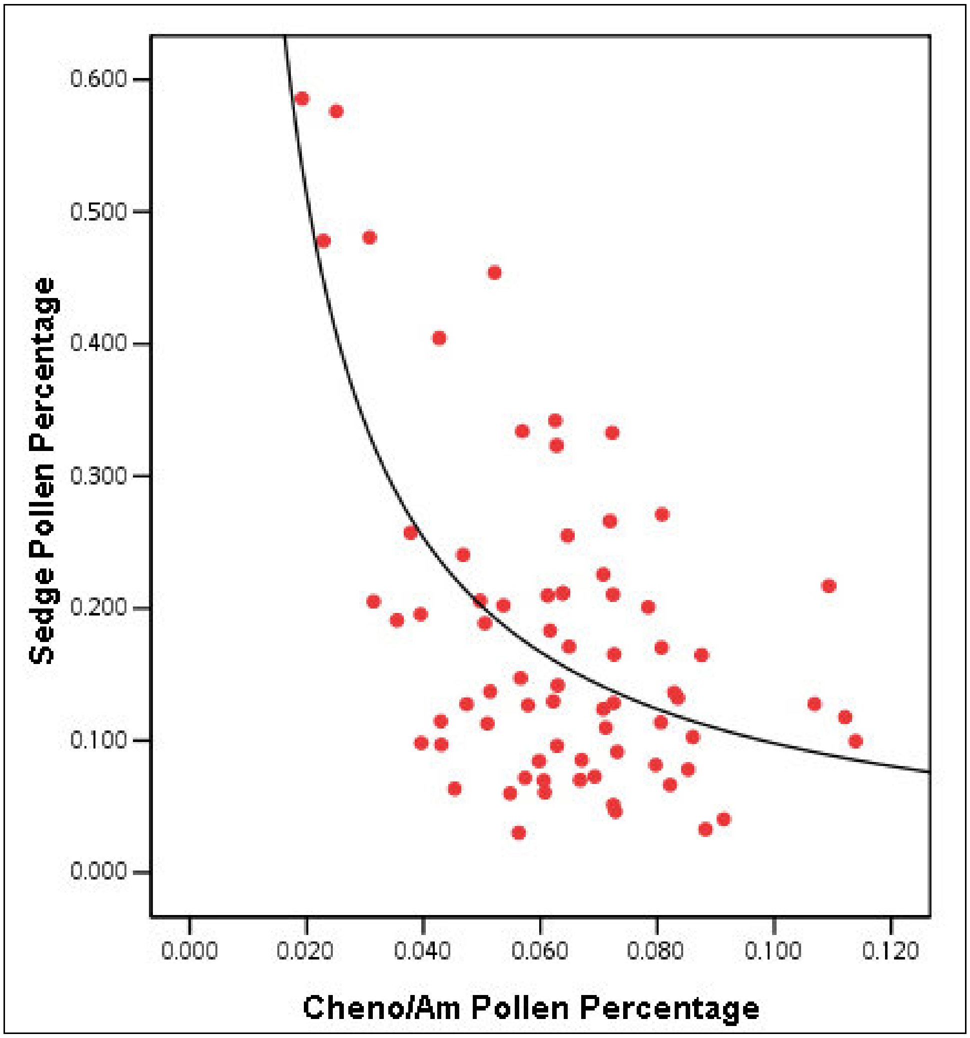

Figure 18. Logarithmic regression of sedge-percentage onto Cheno/Am-percentage for all samples from Beef Pasture Core No. 3 showing a significant negative correlation between the two variables (*r* = .572; *p* < .0005, sedge percentage = - 0.3863 - 0.201*ln(Cheno/Am percentage)).

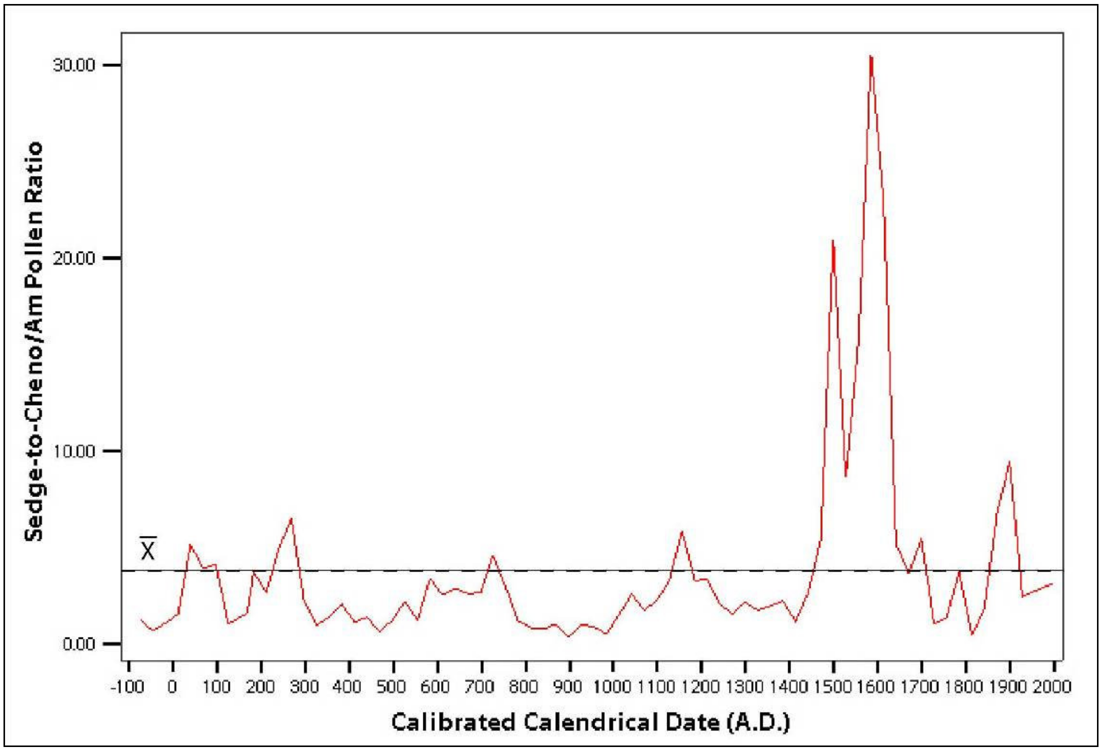

Figure 19. Sedge-to-Cheno/Am pollen ratios for all samples plotted by the sample's estimated calendrical date around the mean ratio (3.75) for the entire assemblage. Increases in this ratio imply increases in winter precipitation.

Table 8. Mean Pollen Ratios between Indicator Taxa for Each Pollen Zone

Zone	Estimated Date Range (cal. B.C./A.D.)	Ponderosa-to-Spruce Pollen Ratio	Sedge-to-Cheno/Am Pollen Ratio
11	A.D. 1721 - 1940	1.42	3.41
10	A.D. 1636 - 1720	2.64	4.77
9	A.D. 1491 - 1635	3.53	19.75
8	A.D. 1406 - 1490	4.76	3.08
7	A.D. 1266 - 1405	1.72	1.94
6	A.D. 1006 - 1265	2.66	2.91
5	A.D. 836 - 1005	1.32	0.78
4	A.D. 576 - 835	2.72	2.65
3	A.D. 291 - 575	1.83	1.46
2	A.D. 36 - 290	1.40	3.76
1	100 B.C. – A.D. 35	1.12	1.16

Pollen Influx Rates of Indicator Taxa

Pollen influx rates of indicator species provide another measure of past changes in regional climates as expressed by the amount of a taxon's pollen deposited within a square centimeter per-year (pollen/cm^2/year). Unlike the frequency and ratio measures, pollen influx rates allow for a comparison of the deposition of a taxon's pollen through time unrelated to other taxa; thus, an increase in a taxon's pollen influx rate indicates that a greater amount of that taxon's pollen was deposited at that location per year, and vice versa. With the exception of ponderosa pine, increases in the pollen influx rate of the indicator taxa used in this study imply that those species were more prevalent around the coring location at that time. I presume that ponderosa pine influx rates will remain relatively constant when compared to the other indicator taxa because of the nature of ponderosa pine pollen dispersal. The fall-out rate of ponderosa pine is approximately twice as slow as that of spruce (Anderson 1970; Erdtman 1969), and slight fluctuations in the lower subalpine forest boundary should not greatly affect the amount of ponderosa pine pollen deposited at Beef Pasture because it typically travels much further than spruce pollen as part of the canopy component of forest pollen dispersal (Moore et al. 1991:12-13; Tauber 1965). As long as this species remains prevalent within the mountain range regardless of its proximity to the coring location, the influx rate of its pollen should remain fairly consistent because the west-to-east trending winds in the region would continually carry ponderosa pine pollen upslope from the adjacent montane forest and its deposition should remain relatively uniform upslope of the montane forest.

As discussed in Chapter 3 and following Petersen (1988), I use pinyon pine pollen influx as the only proxy for inferring prehistoric fluctuations in summer precipitation. Pinyon pine pollen is considerably smaller and lighter than that of ponderosa pine, which entails that its fall-out rate is slower than that of ponderosa pine pollen, and it occurs so far down slope from Beef Pasture that it is likely carried as part of the pollen rain component (Tauber 1965). Influx rates of pinyon pine pollen at Beef Pasture are therefore more or less unrelated to this species' proximity to the coring location. Instead, I assume that pinyon-pine pollen influx fluctuates in response to the number of pinyon trees and their vitality at lower elevations, which is dictated largely by the amount of summer precipitation in the region.

Following Maher (1972a:538-540), the influx rate of a single taxon (X) for a sample is calculated with the following formula:

$$\text{pollen of taxon } X/\text{cm}^2/\text{year} = (NSR) \div V$$

where N = number of *Lycopodium* sp. spores added to the sample

S = sedimentation rate of the sample (cm/year)

R = ratio of the counted pollen grains of taxon X to counted pollen grains of *Lycopodium* sp. in the sample

V = volume of sediment in the sample (3 cc)

Figure 20 presents the pinyon pine pollen influx rates for each sample. Appendix B provides barcharts of the pollen influx rates of the other four indicator taxa used in this study and Appendix C contains the spread of each indicator taxon's influx rate when grouped by zone. Table 9 lists the mean pollen influx rate of each indicator taxa for each zone.

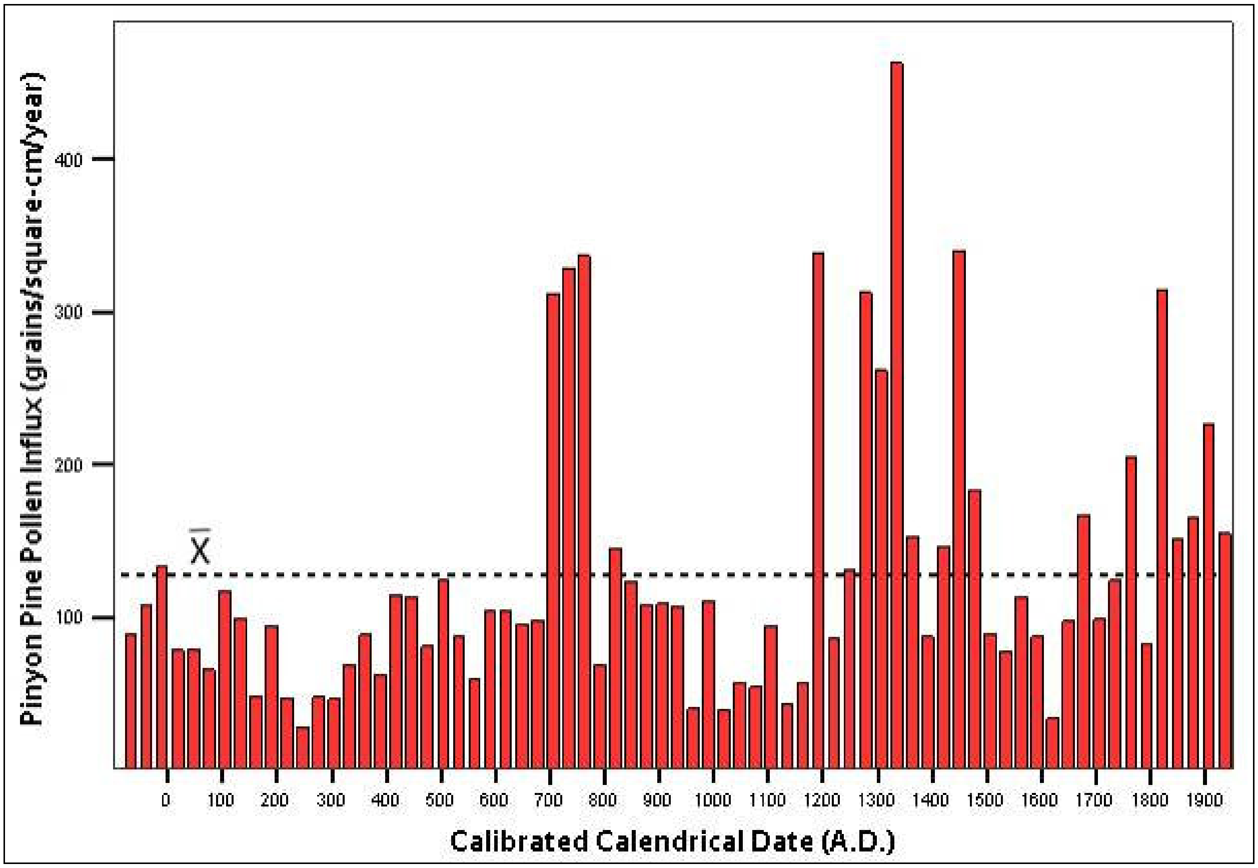

Figure 20. Pinyon pine pollen influx estimates plotted by each sample's calibrated calendrical date around the mean (128 grains/cm^2/year) for the entire assemblage. Increases in this measure imply increases in summer precipitation.

Table 9. Mean Pollen Influx Rates of Indicator Taxa for Each Pollen Zone

Zone	Estimated Date Range (cal. B.C./A.D.)	Spruce	Ponderosa Pine	Sedge	Cheno/Am	Pinyon Pine
11	A.D. 1721 - 1940	677	868	822	281	178
10	A.D. 1636 - 1720	293	705	1,153	247	121
9	A.D. 1491 - 1635	178	653	2,134	140	80
8	A.D. 1406 - 1490	172	741	342	131	223
7	A.D. 1266 - 1405	376	677	332	177	256
6	A.D. 1006 - 1265	186	478	415	140	100
5	A.D. 836 - 1005	643	834	199	251	99
4	A.D. 576 - 835	464	1,242	865	319	177
3	A.D. 291 - 575	421	741	201	144	84
2	A.D. 36 - 290	325	448	314	99	68
1	100 B.C. – A.D. 35	612	693	189	164	120

In this chapter I presented the data obtained from the sedimentological, radiocarbon and palynological analyses. Further, I provided a detailed description of how I used these data to obtain a deposition rate and to assign each sample an estimated calendrical date. The zones that I defined in this chapter provide the basis for interpreting climatic changes through time that I support with statistical measures in the following chapter.

CHAPTER SIX

DISCUSSION

Here, I interpret the pollen data presented in Chapter 5 at two temporal scales. The first considers climatic changes by zone, which I support with statistical measures of difference. I then compare these climatic changes at the zonal scale to other studies of high and low-frequency climatic changes. This comparison reveals that the results of this paleoclimatic reconstruction are supported by other studies consisting of different proxies at different temporal scales. Further, a comparison of the existing tree-ring based precipitation reconstruction to the seasonal proxies used here suggests that several of the well-known droughts may have been dominated by precipitation reductions during certain seasons. These results are of utility to other paleoclimatologists attempting to differentiate seasonal precipitation patterns.

The second part of this chapter compares both zonal and within-zone changes to the paleodemography of the central Mesa Verde region and discusses the interrelationships between population fluctuation and the probable changes in agricultural productivity induced by climatic change. This comparison shows that the major changes in Mesa Verdean paleodemography correspond with significant climatic changes, primarily temperature, which likely affected the region’s agricultural potential. Associated changes in agricultural productivity may have been a major impetus for these paleodemographic shifts. This second part, however, is a tentative discussion because the Village Project has yet to incorporate these new pollen data into its paleoproductivity model. Further, the within-zone climatic changes that I discuss here cannot be verified statistically due to the low sample size of pollen samples at this scale.

Pollen Zones and Inferred Prehistoric Climatic Changes

The following discussion on zonal differences relies on measures of statistical significance, and I employed independent-sample student's *t*-tests, which rely on measures of mean and standard deviation for a population, on pollen frequencies, ratios and influx rates for each zone. Figures 17, 19, and 20 and Appendix B presents these data for each pollen sample in visual format. Appendix C contains boxplots displaying the spreads of these data for each zone; I refer the reader to these boxplots to help visualize the statistical differences that I discuss below in visual format.

Zone 1 (~100 B.C. - A.D. 35)

The analyzed pollen sequence from Beef Pasture initiates in Zone 1. During this period spruce pollen averages 25.5 percent and ponderosa pine pollen averages 28.4 percent of the total pollen sum. Further, the ratio of ponderosa pine-to-spruce pollen averages 1.12 during this period. These measures indicate that during this period, Beef Pasture was enclosed within the subalpine forest, thus, the lower boundary of this forest was at a lower elevation than in many of the subsequent pollen zones. The range (23.1 – 29.3 percent) and average (25.5 percent) of spruce pollen frequencies within this zone are well above the 20-percent average characteristic of the subalpine forests of western Colorado (Fall 1992, 1997b). Because the proportion of sedge pollen in the pollen assemblage is relatively low (8.2 percent), and that the proportion of Cheno/Am pollen is relatively high (6.9 percent), the placement of the subalpine forest boundary below Beef Pasture during this period is most likely due to cooler summer and average yearly temperatures in the Mesa Verde region rather than to greater amounts of winter precipitation. Pinyon pine pollen frequencies average 4.2 percent and pollen influx rates average 120.11 grains/cm^2/year, which are relatively average for this species in the context of the entire core.

Based on these influx rates, the Mesa Verde region experienced an average rate of summer precipitation on a multidecadal scale.

Zone 2 (~ A.D. 36 - 290)

Spruce pollen averages 18.8 percent of the total pollen assemblage in Zone 2, which is significantly less than the spruce frequencies in Zone 1 (t = 4.16, df = 11, p = .006). The spruce influx rate in this zone, averaging 324.56 grains/cm^2/year, is also significantly less than that of Zone 1 (t = 3.43, df = 11, p = .006). The ratio of ponderosa pine-to-spruce pollen averages 1.40, which is also significantly higher than this ratio in Zone 1 (t = -2.26, df = 11, p = .045). Ponderosa pine pollen averages 25.9 percent and its influx rate averages 448.34 grains/cm^2/year in Zone 2, both of which are slightly less than that of Zone 1 but these changes are not statistically significant. Sedge proportions average 18.1 percent in this zone, which is significantly higher than the sedge frequencies in the previous zone (t = -3.09, df = 11, p = .010). The proportion of Cheno/Am in the pollen assemblage averages 5.4 percent while the ratio of sedge-to-Cheno/Am pollen averages 3.76 in Zone 2. The change in the ratio of sedge-to-Cheno/Am pollen between Zones 1 and 2 is also significant (t = -2.89, df = 11, p = .015). Further, the Cheno/Am pollen influx rate, averaging 99.23 grains/cm^2/year, is significantly less than that of the previous zone (t = 2.35, df = 11, p = .038). While the influx rate and frequency of pinyon pine pollen decreases slightly between Zones 1 and 2, these differences are not statistically significant.

When these measures are compared to Zone 1, it appears that the lower boundary of the subalpine forest began to recede upslope during this period. Although the difference in the arboreal composition is small, the lower spruce and slightly higher ponderosa pollen frequencies and influx rates suggest that the number of spruce trees within the vicinity of Beef Pasture had declined while the prevalence of ponderosa pine increased. The changes in sedge and Cheno/Am pollen frequencies and influx rates indicate that the amount of winter precipitation during this zone also increased over the previous period. The higher frequency and influx rate of sedge pollen and the increased ratio of sedge-to-Cheno/Am pollen indicate that Beef Pasture witnessed a period of greater effective winter precipitation that allowed sedge to become a greater component of the forest's understory at the expense of Cheno/Am-species that are indicative of periodic drying of the fen. Thus, while winter precipitation seems to have increased, the lower boundary of the subalpine forest still receded. This strongly suggests that this period became warmer, where spruce began to become succeeded by the advancement of ponderosa pine upslope. Likewise, winter precipitation likely increased, thus, the upward movement of the lower boundary of the subalpine forest occurred regardless of increased amounts of winter precipitation. Summer precipitation, based on measures of pinyon pine pollen, appears to have remained relatively constant on a multidecadal scale between Zones 1 and 2.

Zone 3 (~ A.D. 291 – 575)

Zone 3 is distinguished from the previous zones by a continued increase in the proliferation of ponderosa pine trees and a decrease in the prevalence of sedge around to the Beef Pasture sampling locale. The spruce pollen frequency in Zone 3 averages 16.9 percent and its influx rate averages 324.56 grains/cm^2/year, both of which are slightly less than the previous zone. In contrast, ponderosa pollen frequency averages 30.1 percent and is significantly higher than that of the previous zone (t = -2.59, df = 17, p = .019). The average influx rate of 740.63 grains/cm^2/year for ponderosa pine pollen is also significantly greater than that of the previous zone (t = -2.65, df = 17, p = .017). Furthermore, the ratio of ponderosa pine-to-spruce pollen, averaging 1.83, increased significantly from Zone 2 to Zone 3 (t = 3.01, df = 17, p = .008). There is no statistical difference in the pinyon pollen frequency or influx rate between Zones 2 and 3, which suggests that summer precipitation patterns continued to remain relatively constant on a multidecadal scale from Zone 1 through Zone 3.

The frequency of sedge pollen in Zone 3 is significantly less than that of Zone 2 (t = 5.85, df = 17, p = .000), as frequencies here average only 8.3 percent of the total pollen sum. Moreover, it is fairly likely that sedge pollen influx, averaging 200.97 grains/cm^2/year, decreased from Zone 2 to Zone 3 (t = 1.83, df = 17, p = .084). As expected from the reduction in sedge pollen frequency and influx, Cheno/Am pollen frequencies increased slightly to an average of 5.9 percent and its fairly likely that the Cheno/Am influx rate increased (t = -1.92, df = 17, p = .072), averaging 143.54 grains/cm^2/year here. The ratio of sedge to Cheno/Am pollen averages 1.46, which is significantly lower than the ratio from Zone 2 (t = -3.98, df = 17, p = .001). Interestingly, the distinction between Zones 2 and 3 also occurs near a stratigraphic change in the sediments deposited at Beef Pasture (Table 3), since Zone 3 becomes darker, less red in color and less fibrous in texture than Zone 2. These changes may be attributable to the reduction in sedge around Beef Pasture, as evidenced from the pollen; therefore, the sediments may be comprised of more arboreal detritus than are those in earlier zones. The textural change probably also indicates that Beef Pasture witnessed periods of less winter precipitation, which allowed for greater periodicities of an oxidizing atmosphere that facilitated the increased decomposition of organic matter here than in earlier zones.

During Zone 3, the lower boundary of the subalpine forest continued to recede upslope, a phenomenon initiated during Zone 2. The reduction in spruce pollen frequency and influx, the increase in ponderosa pollen frequency and influx, and the increase in the ponderosa pine-to-spruce pollen ratio support this inference. However, whether or not this movement is linked to increasing temperatures or decreased winter moisture is unclear. Winter precipitation amounts seem to have also decreased during this period, as evidenced by a reduction in sedge pollen frequency and influx, an increase in Cheno/Am pollen frequency and influx, and a reduction in the sedge-to-Cheno/Am ratio. The sediment change near the beginning of this zone also suggests that winter precipitation decreased and resulted in a higher periodicity of sediment drying in the fen, which probably contributed to the increased decomposition of organic material at this time. Considering that there was a significant decrease in sedge pollen frequencies during this zone, and that sedge comprises more than 10 percent of the pollen sum in only one sample from this zone, the reduction in spruce trees at this time is most likely the result of increased periods of soil drought caused by reduced winter precipitation. It is possible, however, that both increased temperatures and reduced winter precipitation contributed to the lower frequency of spruce during this period, but the data only support an argument for increased winter precipitation.

Zone 4 (~ A.D. 576 - 835)

Zone 4 continues a trend of increasing numbers of ponderosa pine trees within the vicinity of Beef Pasture. Although the average spruce pollen influx rate increases slightly to 463.54 grains/cm^2/year, spruce pollen frequencies average 10.6 percent, which is significantly lower than the average frequency observed in Zone 3 ($t = 4.97$, $df = 17$, $p < .001$). Concurrent with a reduction in spruce frequencies, the average frequency of ponderosa pine pollen decreased slightly to 28.3 percent during this period. Ponderosa pine pollen influx, however, increased significantly between Zones 3 and 4 to an average of 1,242.35 grains/cm^2/year ($t = -3.55$, $df = 17$, $p = .002$). Considering that Zone 4 witnessed a significant increase in the ratio of ponderosa pine-to-spruce pollen grains compared to Zone 3 (t = -4.08, df = 17, p = .001), as this ratio averages 2.72 here, the significant reduction in spruce pollen frequency coupled with significant decrease in ponderosa pine pollen influx suggests in fact that spruce became less prevalent around Beef Pasture while ponderosa either remained stable or increased in frequency. Although statistically insignificant, Zone 4 also witnessed an increase in the average frequency of pinyon pine pollen to 4.0 percent of the total pollen sum. Pinyon pollen influx, however, did increase significantly to an average of 177.10 grains/cm^2/year (t = -2.52, df = 17, p = .022). I interpret these changes in pinyon pine pollen percentage and influx as indicators of increased summer precipitation during this zone.

The sedge pollen frequency averages 18.4 percent in Zone 4, a measure that is significantly higher that that of the previous zone (t = 4.26, df = 17, p = .001). Sedge pollen influx rates also increased significantly to an average of 865.23 grains/cm^2/year (t = -3.82, df = 17, p = .001). There is also a fairly significant increase in Cheno/Am pollen frequencies from Zone 3 to Zone 4 (t = -2.08, df = 17, p = .053), averaging here 7.5 percent of the total pollen sum. The influx rate of Cheno/Am pollen is also significantly higher in this zone, averaging 319.23 grains/cm^2/year, than in the previous zone (t = -5.60, df = 17, p < .001). Zone 4 also has significantly higher ratios of sedge-to-Cheno/Am pollen, which average 2.65, when compared to Zone 3 (t = -3.00, df = 17, p = .008). Although the frequencies and influx rates of Cheno/Am pollen are higher in this zone than that of Zone 3, these differences are driven by the upper two samples of this zone, which consist of Cheno/Am frequencies greater than 10 percent and sedge frequencies less than 12 percent. The upper two samples in this zone, therefore, seem to indicate that a change toward reduced winter precipitation occurred during this time.

The measures of arboreal composition suggest that the trend of increased ponderosa and decreased spruce around Beef Pasture witnessed in the previous zones continued during this period. These data evidence that the lower boundary of the subalpine forest continued to recede upslope, mostly likely in response to increasing summer and annual temperatures. Concomitant with the increase in ponderosa around Beef Pasture, winter precipitation seems to have also increased over the previous zone; this suggests that this upward movement of the lower subalpine forest boundary was the result of increased temperatures and not reduced winter precipitation. Winter precipitation, while seemingly greater in amount throughout this zone compared to Zone 3, seems to have decreased near the end of this period. Based on pinyon pine frequencies and influx rates, this period seemingly witnessed an increase in summer precipitation on a multidecadal scale.

Zone 5 (~ A.D. 836 - 1005)

Zone 5 witnessed an increase in the prevalence of spruce trees around Beef Pasture. Averaging 19.2 percent, the frequencies of spruce pollen are significantly higher than the frequencies in Zone 4 (t = 5.92, df = 13, p < .001). Not only is the zonal average nearly twice as high as the previous zone, but the lower range of spruce frequency in Zone 5 is also greater than the highest spruce frequency in Zone 4. Zone 5 also witnessed a fairly significant increase in the influx rates of spruce pollen (t = -1.99, df = 13, p = .068), which average 643.14 grains/cm^2/year in Zone 5. Ponderosa pollen frequencies average 24.9 percent in Zone 5, which is less than the previous zone. The influx rates of ponderosa pine pollen, which average 834.37 grains/cm^2/year in Zone 5, also decreased significantly from Zone 4 to Zone 5 (t = 2.42, df = 13, p = .031). Moreover, the ratio of ponderosa pine-to-spruce pollen in Zone 5 averages 1.32 and is significantly higher than that of the previous zone (t = -5.46, df = 13, p < .0005). Even though the average pinyon pine pollen frequency dropped to 3.0 percent and the average pinyon pine pollen influx rate decreased to 99.35 grains/cm^2/year in Zone 5, these changes are not statistically significant.

Sedge pollen frequencies, which average 6.0 percent of the total pollen sum in Zone 5, are significantly lower than the previous zone (t = 2.37, df = 13, p = .001). Sedge pollen influx rates are also significantly lower in this zone than in the previous one (t = 2.93, df = 13, p = .012), where they decreased here to an average of 198.99 grains/cm^2/year. Cheno/Am frequencies, averaging 7.7 percent in Zone 5, and influx rates, averaging 251.31 grains/cm^2/year in Zone 5, are both slightly higher here than in the previous zone. As expected from reduced sedge frequencies and influx rates along with increased Cheno/Am frequencies and influx rates, the average ratio of sedge-to-Cheno/Am pollen in this zone, averaging 0.78, is significantly lower than that of Zone 4 (t = -3.88, df = 13, p = .002).

The increase in spruce pollen and decrease in ponderosa pollen indicate that Zone 5 witnessed a downward expansion of the subalpine forest. Winter precipitation seems to have been extremely low during this period as well, which is a continuation of the trend witnessed at the end of Zone 4. Since this zone is characterized by such low frequencies and influx rates of sedge, the downward movement of the lower boundary of the subalpine forest here is most likely due to decreased regional temperatures. Considering that the frequency of spruce in this zone is similar to frequencies observed for modern subalpine forest in western Colorado (Fall 1992, 1997b), Beef Pasture was probably enclosed within the subalpine forests at this time and the lower boundary of this forest was below the elevation of Beef Pasture (3,060 m). The lack of winter precipitation during this period may also be evidenced by a stratigraphic distinction in the Beef Pasture sediments at 71 cm below surface (Table 3). Sediments immediately below 71 cm, which comprise the entirety of Zone 5, are less fibrous than sediments immediately above this depth. This greater breakdown in organic texture may be attributable to greater periodicities of soil drying and oxidization, which could contribute to increased decomposition of the peaty materials, and suggests further that there was less winter precipitation during this period. Since there is no statistically significant difference in the measures of pinyon pollen, there does not appear to have been a significant change in low-frequency regime of summer precipitation from Zone 4 to Zone 5.

Zone 6 (~ A.D. 1006 - 1265)

Zone 6 witnessed a reversion to a decreased prevalence of spruce trees around Beef Pasture. Spruce pollen frequencies average 9.3 percent, and they are significantly less than those in Zone 5 ($t = 7.10$, $df = 13$, $p < .001$). Sedge pollen influx rates also decreased significantly to an average of 185.86 grains/cm^2/year in Zone 6 ($t = 6.11$, $df = 13$, $p < .001$). Although the average frequency of ponderosa pine pollen in Zone 6 drops slightly to 23.9 percent of the total pollen sum, this change is not significant. The ponderosa pine pollen influx rates, however, averaging 478.40 grains/cm^2/year here, are significantly lower than in the previous zone ($t = 3.64$, $df = 13$, $p = .003$). The ratios of ponderosa pine-to-spruce pollen average 2.66 and they are significantly higher than the ratios in Zone 5 ($t = -5.92$, $df = 13$, $p < .0005$). While the average pinyon pine pollen influx increased slightly to 99.67 grains/cm^2/year and the average pinyon pollen frequency increased to 4.0 percent in Zone 6, these increases are not statistically significant.

As the pinyon pollen data suggest, there was no apparent change in the summer precipitation regime on a multidecadal scale during this period. Although ponderosa pine pollen influx decreased significantly from Zone 5 to Zone 6, the reductions in spruce frequency and influx along with a lower zonal average of the ponderosa pine-to-spruce pollen ratio suggest that there were fewer spruce trees around Beef Pasture than in the previous zone. The reduction in ponderosa pine influx rate may evidence that the overstory, consisting largely of ponderosa pine, was thinner at this time than in the previous zone. The decreases in spruce pollen frequency and influx along with the increase in the ponderosa pine-to-spruce ratio suggest that the lower boundary of the subalpine forest began to recede upslope once more during Zone 6, and it was most likely located at a higher elevation than that of Beef Pasture (3,060 m).

Sedge pollen frequencies in Zone 6, averaging 19.5 percent of the total pollen sum, are significantly higher than those of Zone 5 ($t = -4.40$, $df = 13$, $p < .001$). The increase in the pollen influx rates of sedge, which average 415.21 grains/cm^2/year in Zone 6, is also fairly significant ($t = -2.12$, $df = 13$, $p = .054$). Furthermore, the lowest range of sedge frequency in this zone is greater than the highest sedge frequency in Zone 5. Cheno/Am pollen frequencies, which average 6.9 percent here, are also slightly less than those observed in Zone 5. The Cheno/Am pollen influx rates, averaging 140.26 grains/cm^2/year here, are significantly lower than those of Zone 5 ($t = 3.98$, $df = 13$, $p = .002$). Likewise, the ratios of sedge-to-Cheno/Am pollen in this zone average 2.91, which is nearly four time higher than that of Zone 5, and this difference is highly significant ($t = -3.88$, $df = 13$, $p = .002$).

As sedge and Cheno/Am pollen frequencies and influx rates suggest, along with the increase in the sedge to Cheno/Am pollen ratios, winter precipitation increased on a multidecadal scale during this zone. Similar to Zones 2 and 4, the upslope movement of the lower boundary of the subalpine forest during this time appears to be independent of the effects of winter precipitation. Therefore, the upward movement of the subalpine forest's lower boundary is mostly likely attributable to increased regional temperatures and not soil drought during this period.

Zone 7 (~ A.D. 1266 - 1405)

Spruce pollen frequencies, averaging 14.6 percent in Zone 7, are significantly higher than in Zone 6 (t = -4.71, df = 12, p = .001). Spruce pollen influx rates in Zone 7 average 375.85 grains/cm^2/year, and this increase over the previous zone is significant (t = -3.13, df = 12, p = .001). Ponderosa pine pollen frequencies and influx rates increase slightly from Zone 6 to 7, averaging here 25.2 percent and 677.37 grains/cm^2/year respectively, however these differences are not statistically significant. The ponderosa pine-to-spruce pollen ratios in Zone 7 average 1.72 and are also significantly lower than those of Zone 6 (t = -3.74, df = 12, p = .003). Pinyon pine pollen frequencies, averaging 9.6 percent of the total pollen sum, are significantly higher here than in the previous zone (t = -3.50, df = 12, p = .004). Further, the pinyon pine pollen influx rates of Zone 7 are significantly higher that those of Zone 6 (t = -2.45, df = 12, p = .031), as here they average 255.65 grains/cm^2/year.

Sedge pollen frequencies in Zone 7 average 14.1 percent, which is lower than the previous zone but not significantly so. Sedge pollen influx rates also decrease from Zone 6 to 7, as here they average 332.50 grains/cm^2/year. This difference, however, is also not statistically significant. The average Cheno/Am pollen frequency in Zone 7 increased slightly to 7.3 percent while the average Cheno/Am pollen influx rate increased to 177.38 grains/cm^2/year, but while these are slightly higher than the previous zone the differences are not significant. Further, the sedge-to-Cheno/Am pollen ratios, averaging 1.94 in Zone 7, decreased slightly from the previous zone, but this change is also not statistically significant.

The reductions in the measures of sedge pollen deposition combined with the increases in Cheno/Am pollen deposition suggest that winter precipitation possibly decreased in Zone 7, however, these changes are slight and not statistically significant. This suggests to me that the coring location may have experienced lower winter precipitation amounts, on a multidecadal scale, during the temporal span represented in Zone 7, but this change is not supported by statistical measures. Since the prevalence of spruce around Beef Pasture apparently increased in this zone, and sedge may have decreased, the downward movement of the lower boundary of the subalpine forest at this time was likely driven by reduced summer and yearly temperatures and not an increase in winter precipitation. These reduced temperatures may have been a localized result of the Little Ice Age. The effects of the Little Ice Age in the Greater Southwest, however, do not conform to those witnessed in Europe (see Dean 1994), and as discussed in more depth below, it is becoming an increasingly problematic concept in western North America.

The increase in pinyon pine prevalence at lower elevations in the Mesa Verde region, as inferred from the pinyon pine pollen measures, suggests that this period witnessed more summer precipitation. This zonal average is obfuscating the effects of the 20-year Great Drought at the end of the thirteenth century. While tree-ring records document this drought rather well, it is poorly expressed in the pollen record. Both the pinyon pine pollen frequencies and influx rates, however, are low during the mid-twelfth century, suggesting that the estimated dates for this time may be slightly incorrect. Figure 14 shows, however, that the residuals derived from regression equation used to assign samples with estimated dates are minimal from approximately A.D. 1000 and 1425. This suggests that the estimated dates for this portion of the pollen profile are very reliable.

Benson et al. (2006) suggest that although the Great Drought was rather long in duration, the magnitude of the reduction in summer precipitation amounts was not as great as many of the other droughts in the southwest, such as the mid-twelfth century drought. The pollen record, however, suggests that this period may have witnessed a reduction in winter precipitation. Since distinguishing between winter and summer precipitation from tree-ring records is problematic, we are unsure as to which of these seasons witnessed reductions in precipitation during the Great Drought. The pollen record suggests that it was a combination of slight reductions in the precipitation of both seasons, at least on a multidecadal scale, however, it appears to have been dominated by winter-dominated droughts. This is likely why the Great Drought is poorly represented in the summer precipitation reconstruction presented here.

Zone 8 (~ A.D. 1406 – 1490)

In Zone 8 spruce pollen frequencies average 7.1 percent and are significantly lower than in the previous zone (*t* = 5.12, *df* = 6, *p* = .002). Spruce pollen influx rates are also lower, averaging here 171.85 grains/cm^2/year, and this reduction is fairly significant (*t* = 1.97, *df* = 6, *p* = .097). Likewise, ponderosa pollen frequencies average 31.7 percent in Zone 8, noticeably higher than those observed in Zone 7. The ponderosa pine pollen influx rates in Zone 8 average 741.34 grains/cm^2/year and are slightly lower than the previous zone. Although most of the differences in measures of spruce and ponderosa pine pollen between Zones 7 and 8 are not statistically significant, due likely to the small sample size in Zone 8, the ratios of ponderosa pine-to-spruce pollen, averaging 4.76 here, are significantly higher than in Zone 7 (*t* = -3.30, *df* = 6, *p* = .016). The magnitude of this change, displayed visually in Figure 17, may not express accurately the actual change in the overstory around Beef Pasture. Pinyon pine pollen frequencies, averaging 9.2 percent, and influx rates, averaging 223.37 grains/cm^2/year, are relatively similar to the previous zone.

Sedge pollen frequencies, averaging 14.3 percent, and influx rates, averaging 341.64 grains/cm^2/year, are nearly identical to the previous zone. Cheno/Am pollen frequencies, averaging 9.2 percent, and influx rates, averaging 130.95 grains/cm^2/year, are also very similar to those of Zone 7. While the ratio of sedge-to-Cheno/Am pollen averages 3.08 in Zone 8, the increase over the previous zone is not significant. The lack of any significant changes in the sedge and Cheno/Am pollen data between Zones 7 and 8 is likely the result of a small sample size for Zone 8. As Figure 19 shows, Zone 8 appears to have begun a trend toward increased winter precipitation around Beef Pasture with a slight perturbation at the end of this zone.

While it is unclear as to whether or not winter precipitation amounts increased during Zone 8, the increased prevalence of ponderosa pine around Beef Pasture is likely due to an increase in regional temperatures because otherwise it would have been the result of decreased winter precipitation, which the pollen record does not support. Although it is unclear as to whether or not winter precipitation amounts did or did not increase during this zone, the data do not demonstrate any likelihood of reduced winter precipitation. The pinyon pollen data suggest that the increased amounts of summer precipitation that began at the beginning of the fourteenth century continued to persist throughout this zone with relatively little change on a multidecadal scale. Figure 20, however, shows a reduction in pinyon pollen influx at the temporal boundary between Zones 7 and 8 (~A.D. 1400), which may suggest a period of reduced summer precipitation at this time.

Zone 9 (~ A.D. 1491 - 1635)

Zone 9 witnessed a fairly significant reduction in the frequency of spruce pollen from the previous zone ($t = 2.24$, $df = 6$, $p = .066$), and these average 4.7 percent in this zone. Spruce pollen influx rates, averaging 178.45 grains/cm^2/year in Zone 9, are relatively unchanged over the previous zone. Ponderosa pine pollen frequencies average 15.4 percent in Zone 9, which is significantly less than the previous zone ($t = 4.23$, $df = 6$, $p = .005$). Ponderosa pine pollen influx rates are also lower here, where they average 653.02 grains/cm^2/year, than in Zone 8. With an average of 3.53 for Zone 9, the ratios of ponderosa pine-to-spruce are also lower than the previous zone, however, the difference is not significant. Pinyon pine pollen frequencies, averaging 2.2 percent here, are significantly less than the previous zone ($t = 7.13$, $df = 6$, $p = .000$). Likewise, the pinyon pollen influx rates are significantly lower here, where they average 79.85 grains/cm^2/year, than in Zone 8 ($t = -3.08$, $df = 6$, $p = .022$).

The fact that both spruce and ponderosa pollen frequencies declined from Zone 8 to 9 is likely due to a large increase in the deposition of sedge pollen at Beef Pasture, which has suppressed the other pollen frequencies. In fact, there is no statistically significant difference between the pollen concentration values for spruce and ponderosa between Zones 8 and 9 ($t = -0.354$, $df = 6$, $p = .735$), suggesting that the amount of their pollen deposited at Beef Pasture did not change between these two zones and that the increase in sedge is responsible for the low frequencies of spruce and ponderosa pollen in Zone 9. With an average of 51.6 percent, the frequencies of sedge in Zone 9 are nearly four times higher than sedge frequencies in the previous zone, and this difference is significant ($t = -9.04$, $df = 6$, $p < .0005$). Sedge pollen influx rates, averaging 2,134.16 grains/cm^2/year, are also significantly higher here than in Zone 8 ($t = -3.08$, $df = 6$, $p = .022$). As expected from the increased sedge frequencies, there is a fairly significant reduction in the frequencies of Cheno/Am pollen, which average 3.0 percent here, from Zone 8 to 9 ($t = 2.06$, $df = 6$, $p = .085$). Although the Cheno/Am pollen influx rates are slightly higher here, averaging 140.33 grains/cm^2/year, than in the previous zone, the difference is not significant. The ratios of sedge-to-Cheno/Am pollen, averaging 19.75 in Zone 9, are significantly higher than the previous zone ($t = 3.37$, $df = 6$, $p = .015$).

While the large increases in sedge pollen frequencies and influx rates suggest that this period witnessed a very large incredible increase in winter precipitation over the previous zone, the magnitude of the climate change may not be as drastic as the pollen record indicates. Increased winter precipitation is further supported by the texture of the sediments in this zone, which are very fibrous and indicative of perennially wet conditions that inhibit vegetational decomposition. Although spruce and ponderosa frequencies are lower in this zone than in Zone 8, a lack of significant statistical differences suggests that the overstory around Beef Pasture did not change considerably between Zones 8 and 9. Figure 17, however, suggests that Zone 9 was highly variable with regard to temperature, as the ratio of ponderosa pine-to-spruce pollen oscillates considerably. Therefore, Zone 9 differs from Zone 8 in the periodicities of low-frequency temperature changes, as here they appear to occur more frequently with perhaps greater magnitudes of change. Based on the pinyon pollen data, it also appears that the Mesa Verde region experienced a reduction in the amount of summer precipitation on a multidecadal scale here when compared to the previous zone.

Zone 10 (~ A.D. 1636 - 1720)

In this zone, spruce pollen frequencies average 7.7 percent, which is a fairly significant increase from the previous zone ($t = -2.31$, $df = 6$, $p = .060$). Although spruce pollen influx rates increased over the previous zone, averaging 292.95 grains/cm^2/year in Zone 10, this increase is not significant. Likewise, increases in ponderosa pollen frequencies, averaging 19.2 percent here, and influx rates, averaging 705.05 grains/cm^2/year here, over the previous zone are not statistically significant. While the ratios of ponderosa pine-to-spruce pollen decreased in Zone 10, where they average 2.64, this change is not statistically significant, likely due to the low sample size. The average pinyon pine pollen frequency of 3.2 percent and average influx rate of 120.70 grains/cm^2/year for Zone 10 are both slightly higher than the previous zone, however, the differences are not statistically significant.

Sedge pollen frequencies dropped significantly from Zone 9 to 10 (t = 5.09, df = 6, p = .002), as they average 30.9 percent here. Sedge pollen influx rates, averaging 1,153.39 grains/cm^2/year in Zone 10, are considerably lower than the previous zone. Cheno/Am pollen frequencies average 6.6 percent in Zone 10, which is twice as high and significantly different than those of Zone 9 (t = -4.40, df = 6, p = .005). Cheno/Am pollen influx rates, averaging 246.69 grains/cm^2/year here, are also considerably higher than those of the previous zone. Similarly, the ratios of sedge-to-Cheno/Am pollen in Zone 10 average 4.77, and they are significantly less than those of Zone 9 (t = 3.07, df = 6, p = .022). Likewise, the sediments of Zone 10 (Table 3) consist of organic material that is more thoroughly decomposed than those of the previous zone, which suggests that the ground was exposed to a higher periodicity of drying and oxidization that facilitated organic breakdown.

Zone 10 is distinguished from the previous zone by a possible downward movement of the lower boundary of the subalpine forest, presumably due to reduced regional temperatures. The lack of statistically significant changes in the arboreal pollen measures, however, is likely due to a small sample size and extreme variability in measures. Similar to Zone 9, this period of possibly reduced temperatures was likely interrupted by periodic episodes of low-frequency warming phases as the variability in the Zone 10 portion of Figure 17 suggests. Even though sedge pollen frequencies, influx rates, and the ratio of sedge-to-Cheno/Am pollen decrease from Zone 9 to Zone 10, which evidence a reduction in winter precipitation, Zone 10 is still characterized by a relative high presence of sedge pollen in the sediments. Thus, the downward movement of the subalpine forest may be related to both a decrease in regional temperatures and relatively high amounts of winter precipitation during this period.

Since the low-frequency reduction in winter precipitation appears to have occurred at a fairly constant rate (Figure 19), it is possible that spruce trees advanced upslope on several occasions during Zone 10 (Figure 17) due to various low-frequency reductions in temperature. Using tree-ring records from northern Arizona, Salzer and Kupfmueller (2005) identified two high-frequency phases of extreme warmth and two high-frequency phases of extreme cold that would have occurred during the temporal span of Zone 10. Figure 17 shows similar low-frequency phenomena in the ponderosa pine-to-spruce pollen ratio that may be due to the climatic perturbations witnessed in the tree-ring record. The pinyon pine pollen data suggest that there was no significant change in the low-frequency regime of summer precipitation between Zones 9 and 10.

Zone 11 (~ A.D. 1721 - 1940)

I expect that the majority of post-depositional disturbance occurred in Zone 11 given its historical age and the history of human activity and land disturbance at Beef Pasture noted in Chapter 2. Therefore, there is a possibility that the vegetational changes evidenced by the pollen data are unrelated to climatic change, however, such a possibility should be confined to the later portion of this zone (post-A.D. 1880). In this zone, spruce pollen frequencies average 15.5 percent and these values are significantly higher than those observed in Zone 10 ($t = 2.98$, $df = 9$, *p* = .015). Spruce pollen influx rates, averaging 676.98 grains/cm^2/year here, are also significantly higher than those in Zone 10 (*t* = -2.63, *df* = 9, *p* = .028). Ponderosa pine pollen frequencies average 20.6 percent and influx rates average 867.55 grains/cm^2/year, neither of which is significantly higher than the previous zone. As expected from increases in spruce pollen measures with relatively stable ponderosa pine pollen measures, there is a significant decrease in the ratio of ponderosa pine-to-spruce pollen between Zones 10 and 11 (*t* = -2.99, *df* = 9, *p* = .015), where the average ratio for Zone 11 is 1.42. Pinyon pine pollen frequencies average 4.2 percent and influx rates average 177.98 grains/cm^2/year in Zone 11, both of which are slightly higher than the previous zone but these differences are not significant.

Sedge pollen frequencies experienced a fairly significant decrease from Zone 10 to 11 (*t* = -1.96, *df* = 9, *p* = .082), as here they average 17.4 percent. Sedge pollen influx rates are also lower in Zone 11, where they average 821.62 grains/cm^2/year. Cheno/Am pollen frequencies average 6.8 percent, which is nearly identical to the average Cheno/Am pollen frequency observed in Zone 10. Cheno/Am pollen influx rates, too, are very similar to those observed in Zone 10, as here they average 821.00 grains/cm^2/year. The ratios of sedge-to-Cheno/Am pollen average 3.41, and are lower than the previous zone, but this change is not statistically significant.

Zone 11 witnessed the continued downward movement of the lower boundary of the subalpine forest that began in Zone 10. While sedge frequencies and the ratio of sedge to Cheno/Am pollen declined from Zone 9 to Zone 10, these changes are probably related to historical land modification and grazing within the vicinity of Beef Pasture in the later portion of this zone. Using historical records, Petersen (1988) has made a sound case for increased winter precipitation amounts as the causal mechanism for the downward expansion of the subalpine forest since the 1890s.

Even though sedge frequencies are low in Zone 10 and the downward expansion of the subalpine forest during this period is likely linked to increased winter precipitation, which counters the supposition that increased sedge propagation is tied to higher amounts of winter precipitation, the use of this proxy prior to historical modification around Beef Pasture is sound. If grazing and land modification resulted in the consistent removal of sedge around Beef Pasture, the dichotomy between increased winter precipitation argued by Petersen (1988) and low sedge values since the 1890s is not surprising. However, this dichotomy demonstrates how misleading inferences could develop from a lack of knowledge about the history of the sampling locale. Likewise, linking the downward movement of the subalpine forest solely to increased winter precipitation, as witnessed in the recent past, may be unfounded. Given that logging has occurred in the La Plata Mountains quite frequently in the past 125 years, one is left to wonder what effect this has had on the composition of the subalpine and montane forests and their pollen assemblages. It may be that the downward movement of the subalpine forest in historic times is also related to forest succession and management practices associated with clearcutting.

The wide ranges in Cheno/Am and sedge pollen frequencies in Zone 11 suggest that the sediments of Beef Pasture witnessed extremely divergent moisture conditions at this time, ranging from very wet to very dry. The sediments of this zone seem to be more fully decomposed that prior deposits (Table 3), which further supports the notion of frequent wetting and drying around the sampling locale during this period. The upper six centimeters of sediment in this zone consist of a gleyed *gytjja*, which indicates that the immediate environment was one of frequent submersion under standing water. The deposition of this sediment is probably the result of seasonal ponding due to the construction of a water-retention feature in 1940. This is further evidenced by the presence of cattail in the uppermost sediments.

Cattail favors habitats characterized by high levels of phosphate, such as areas heavily utilized by cattle. Since the water retention feature at Beef Pasture serves as a water-tank for cattle, the presence of cattail at Beef Pasture is likely due to their presence, which is an indirect consequence of the presence of standing water. Petersen and Mehringer (1976) did not identify cattail pollen in the sediments they extracted from Beef Pasture in 1973, which suggests that the presence of cattail began after the modification of the water retention feature during the latter months of 1973.

The presence of cattail only in the uppermost deposits, and the fact that very little of this pollen seems to have moved into deeper sediments suggest that the possible effects of cattle on the Beef Pasture pollen sequence, as discussed in Chapter 2, are minimal. If cattle had severely disturbed Beef Pasture's sediments through trampling and grazing, then I expect that cattail, the only plant with a modern occurrence attributable to the presence of cattle, would be found at depths pre-dating the construction of the water tank. The minimal translocation of cattail pollen in the Beef Pasture pollen record (Figure 16) suggests that this did not occur to any great extent. Further, the little evidence for such disturbance is contained to the uppermost deposits known to have been disturbed through historical activities. The fibrous nature of woody sedge peat has most likely prevented the majority of disturbance that would be created by cattle trampling because, unlike mud, this type of sediment can support considerable weight without disturbing the sediment's structure. This leads me to conclude that the effects of cattle on Beef Pasture's pollen record are minimal.

Modern Era (~A.D. 1941 - 2005)

The surface sample collected from the periphery of the Beef Pasture sampling locale consists of extremely low frequencies of spruce (2.1 percent) and ponderosa pine (12.2 percent) pollen and noticeably high frequencies of grass (14.7 percent) and *Liguliflorae* sp. (3.4 percent) when compared to other samples. While the surface sample was intended to provide a modern reference from which extrapolations into the past could be made, the results suggest that it does not serve as an appropriate proxy for paleoenvironmental conditions at Beef Pasture. Likewise, I did not include this sample in Zone 11 because its pollen frequencies are quite different than those of any other sample. Since we collected this sample in August, which is right after the time that many of the local species pollinate, it is possible that the high frequency of grass pollen is due to the limited time that these pollen grains have been subjected to weathering.

The anomalous frequencies in this sample may also be related to the fact that we pinch-sampled in various places, and no pinch sample was taken directly from the coring location. The vegetation around many of the areas that we pinch-sampled, such as the edge of the fen, the earthen dam, and next to the road, is unlike that of the coring location and these locations likely contain pollen of species (e.g., grass) that do not occur directly atop of the coring location. In fact, this sample contains the only raspberry (*Rubus* sp.) pollen (0.2 percent) I identified in the entire pollen profile from Beef Pasture, and this is likely due to the variable locations of pinch samples, some of which were elevated out of the fen's moist sediments. The pinch samples, therefore, appear to be more representative of the local vegetation outside of the fen's moist sediments than the vegetation in the fen.

Paleoclimate Summary and Comparison to Other Studies

The composite analysis of changing pollen frequencies, ratios and influx rates of the indicator taxa through time has enabled me to reconstruct the climatically dictated vegetational assemblage around Beef Pasture for the past 2,100 years. Since the successful, long-term (> 20 years) propagation of the indicator taxa used in this study depends largely on the low-frequency climatic variables that I wish to elucidate, changes in the prevalence of these taxa around Beef Pasture represent low-frequency fluctuations in the paleoclimatic regime of the region. The use of several statistical measures on the data from the pollen assemblage, and the compatibility of the results, provides a more robust basis for paleoenvironmental inferences than what would have been possible from a single measure or fewer indicator taxa. Likewise, the 16 radiocarbon samples allow me to place the results in a well-controlled temporal context, the best yet constructed for pollen data from the past 2,100 years in North America. Although the magnitude of the paleoclimatic changes evident in the pollen record cannot be accurately measured with such proxies, I have identified ordinal differences in winter precipitation, summer precipitation and regional temperature through time that likely affected agricultural paleoproductivity at lower elevations within the Mesa Verde Region.

Using pollen data from central Colorado, Fall (1997b) has argued that the modern climate of this area was established by A.D. 1, however, she did observe slight fluctuations in regional temperatures over the past 2 millennia based on fluctuations in the upper boundary of the subalpine forest. Direct correlations between her analysis and the one presented here, however, should not be expected due to vagaries in local environments and geography (Meyer 1992). My analysis of the pollen assemblage of Beef Pasture core No. 3 identifies four low-frequency reductions in regional temperatures and four low-frequency increases in regional temperatures over the past 2,100 years (Table 10). Along with these temperature fluctuations, my results also identify five low-frequency reductions and four low-frequency increases in winter precipitation (Table 11). The observed fluctuations in summer precipitation (Figure 20) do not conform well to the zone-based analysis, however, significant changes did occur at the zonal level. To better pinpoint when these changes actually began to occur, I collapsed these data into periods (Table

12) based on changes observed in Figure 20 that are verified by statistically significant differences between the zones. Therefore, the periods listed in Table 12 deviate from those defined by the 11 zones because this grouping better reflects the observed trends. As Table 12 shows, I identify two low-frequency reductions in summer precipitation and three low-frequency increases in summer precipitation.

The previous discussion of zonal differences relied largely on statistical measures of difference. These zonal changes, however, obfuscate variability within the zones that is more in-tune with the temporal resolution of the archaeological record and possibly more relevant to estimates of agricultural paleoproductivity. The following discussion considers within-zone changes in the measures of the indicator taxa, but statistical procedures are inappropriate due to low sample sizes. Comparisons to the higher resolution tree-ring records and Petersen's (1988) pollen-based paleoclimatic reconstruction from the area, however, do provide support for several within-zone changes inferred from the pollen data.

Temperature

Petersen's (1988) study of the pollen assemblage at Beef Pasture and Twin Lakes is the only other palynological investigation from the region that has critically evaluated the climatic conditions of the past 2,000 years. Petersen inferred from his data that the region experienced a period of cool temperatures from 900 B.C. to A.D. 500. My results are compatible with those of Petersen, where here the beginning of the paleoclimatic sequence initiates with a period of extremely low temperatures from 100 B.C. to A.D. 35 (Figure 17; Table 10). Although I observe an increase in regional temperatures between A.D. 36 and 575, these temperatures were also extremely low in comparison to other periods. My data suggest further that a considerable increase in regional temperatures occurred after A.D. 575, a phenomenon that initiated around

Table 10. Low-frequency Changes in Regional Temperatures[a]

Estimated Date-Range	Zone(s)	Relative Change
100 B.C. – A.D. 35	1	low
A.D. 36 – 575	2-3	increase
A.D. 576 – 835	4	increase
A.D. 836 - 1005	5	decrease
A.D. 1006 – 1265	6	increase
A.D. 1266 – 1405	7	decrease
A.D. 1406 – 1490	8	increase[b]
A.D. 1491 – 1635	9	variable[b]
A.D. 1636 – 1720	10	decrease[b]
A.D. 1721 - 1940	11	decrease

[a] relative changes listed in the table are fluctuations from the previous period, not a comparison to modern conditions.

[b] low-frequency oscillations between cooler and warmer periods are recurrent and highly variable during this period

Table 11. Low-frequency Changes in Winter Precipitation[a]

Estimated Date-Range	Zone(s)	Relative Change
100 B.C. – A.D. 35	1	low
A.D. 36 – 290	2	increase
A.D. 291 – 575	3	decrease
A.D. 576 - 785	4	increase
A.D. 785 – 1005	5	decrease
A.D. 1006 – 1265	6	increase
A.D. 1266 – 1490	7-8	decrease
A.D. 1491 – 1635	9	increase
A.D. 1636 – 1720	10	decrease
A.D. 1721 - 1940	11	decrease

[a] relative changes listed in the table are fluctuations from the previous period, not a comparison to modern conditions.

Table 12. Low-frequency Changes in Summer Precipitation[a]

Estimated Date-Range	Zone(s)	Relative Change
100 B.C. – A.D. 700	1-4	moderate
A.D. 701 – 780	4	increase
A.D. 781 – 1180	4-6	decrease
A.D. 1181 - 1490	6-8	increase[b]
A.D. 1491 – 1750	9-11	decrease[b]
A.D. 1751 – 1940	11	increase

[a] relative changes listed in the table are fluctuations from the previous period, not a comparison to modern conditions.

[b] low-frequency oscillations between periods of wetter and drier summers are recurrent and highly variable during this period

A.D. 36 and continued until approximately A.D. 835 (Figure 17; Table 10). This inference is also supported by both the pollen record at Twin Lakes, Colorado and the Almagre Mountain tree-ring record (Petersen 1988:Figure 51).

After A.D. 835, the Mesa Verde region experienced a reduction in regional temperatures that apparently reached a nadir from A.D. 900 to 950 with cool conditions lasting until about A.D. 1005 (Figure 17; Table 10). Although Petersen's measure for regional temperatures, the conifer-to-non-arboreal pollen ratio at Twin Lakes, does not demonstrate this temperature low, it is expressed rather well in the Almagre Mountain tree-ring record (Petersen 1988:Figure 51). This fluctuation is not represented in the Twin Lakes record because there was only one pollen sample analyzed from this period. In fact, the Twin Lakes pollen record is so coarse that Petersen (1988:100) was reluctant to use it as a proxy for temperature change at this time, instead relying on the Almagre Mountain tree-ring record to infer temperature changes from A.D. 550 to 1970.

The pollen record at Beef Pasture documents a warmer period from A.D. 1006 to 1265 (Table 10), which was interrupted by a short period of cooling centered around A.D. 1090 and a consistent decline in temperatures beginning around A.D. 1200 (Figure 17). Once again, while the Twin Lakes pollen record is too coarse to infer paleoclimatic changes, the Almagre Mountain tree-ring record does indicate a warming period around A.D. 1000, a cooling period centered on A.D. 1100 and a return to higher temperatures until A.D. 1200 (Petersen 1988:Figure 51).

After A.D. 1200, regional temperatures remained relatively low until just after A.D. 1400, at which time a period of warming began and continued until the mid-1600s (Figure 17; Table 10). These results are supported by the decrease in the conifer-to-non-arboreal pollen ratio from Twin Lakes and the Almagre Mountain tree-ring record (Petersen 1988:Figure 51). The extreme oscillations in the later portion of this period seen in Figure 17, however, suggest that between A.D. 1450 and 1700 regional temperatures varied considerably on a low-frequency scale. Although this degree of variability is unlike any other portion of the Beef Pasture pollen record, it is also evident in the Almagre tree-ring record (Petersen 1988:Figure 51), where the durations and magnitudes of the fluctuations are highly variable.

The cooling period that began in the mid-1600s continued until about A.D. 1825, when a return to higher temperatures occurred (Figure 17; Table 10). Although Figure 17 suggests that a period of cooling occurred around the early 1900s, these samples of recent age may not accurately reflect the overstory around Beef Pasture at this time because we do not know what effect logging had on the forest structure and its pollen assemblage. Petersen (1988:101) suggests that regional temperatures began to increase in the 1850s. The Almagre Mountain tree-ring record documents a period of warming from A.D. 1700 to 1800, followed by a temperature low centered on the mid-1800s which is followed by a return to high temperatures. While the Beef Pasture pollen record expresses this temperature low rather well, it does not identify the period of warming right before it. Possible explanations for this disjunction between the two proxies are that these high-frequency temperature changes developed independently of the low-frequency pattern or that the warming trend around Almagre Mountain (350 km ENE) did not occur in the Mesa Verde region. It may also be that the Almagre Mountain tree-ring record has over-estimated the magnitude of local temperature increase at this time.

The Medieval Warm Period (A.D. 1000 – 1250) (Dean 1994; Lamb 1977) is evidenced here in Figure 17 and Table 10, where temperatures remained relatively high throughout the eleventh, twelfth, and early thirteenth centuries. However, several short periods of cooling occurred within this period, as is evidenced here as well as in other temperature reconstructions from the Colorado Plateau (e.g., Salzer and Kipfmueller 2005). The Little Ice Age (A.D. 1250 – 1850), which occurred worldwide but at slightly different times (Bradley 2000:1353; Grove 1988) and with different effects (Dean 1994; Van West and Dean 2000:27-28), is evidenced in the Beef Pasture pollen record (Figure 17). Similar to the Medieval Warm Period, however, the Little Ice Age was not a period of consistently low temperatures, but was characterized by highly variable temperatures (see also Matthews and Briffa 2005). Based on the pollen evidence presented here, the Mesa Verde region also experienced extreme variability in regional temperatures during the Little Ice Age, which is also supported by other studies from the Colorado Plateau (e.g., Salzer and Kipfmueller 2005). From a comparison of 112 paleoclimatic records from across the globe, Mann et al. (1998) could only identify two worldwide cold periods since A.D. 1400: one centered in the 1400s and the other in the 1800s. These lows are observed here in Figure 17. My results combined with those of others (Salzer and Kipfmueller 2005; Van West and Dean 2000) suggest that the traditional concept of the Little Ice Age is a problematic construct when applied to the Southwest.

Winter Precipitation

I infer an initial period of low winter precipitation from 100 B.C. to A.D. 35 in the Beef Pasture pollen record, which was followed by an increase in winter precipitation at A.D. 36 (Figure 19; Table 11). This increase persisted until approximately A.D. 290, and there may have been a short period of reduced winter precipitation around A.D. 150 (Figure 19). After A.D. 290, the Mesa Verde region experienced a reduction in winter precipitation until about A.D. 575. Petersen (1988:99-100) also documented an increase in winter precipitation after 200 B.C that persisted until A.D. 575. Inspection of Petersen's (1988:Figure 51) results also support my inferences of a short period of reduced winter precipitation around A.D. 150 and a general reduction in winter precipitation beginning around A.D. 300 that culminated in an extreme low centered on A.D. 550.

A subsequent increase in low-frequency winter precipitation persisted until the mid-700s (Figure 19; Table 11), however, this increase did not match the winter precipitation high of the mid-200s. This period of low winter precipitation continued until about A.D. 1005, at which time the region experienced a return to higher winter precipitation rates. Although this increase peaked around A.D. 1200, short periods of reduced winter precipitation may have occurred around A.D. 1100. While winter precipitation rates began to decline after A.D. 1200, they remained relatively high until the mid-1200s, at which time they plummeted and remained low until about A.D. 1490. Winter precipitation amounts increased once more after A.D. 1490 and remained relatively high until the mid-1600s, however, Figure 19 likely misconstrues the magnitude of this increase. After A.D. 1635, the Mesa Verde region experienced a decline in winter precipitation, and this trend continued until the early twentieth century. However, this period of low winter precipitation may have been interrupted by short periods of increase in the late 1700s and late 1800s.

My inferences about the winter precipitation of the Mesa Verde region are strongly supported by other research. Petersen documented an increase in winter precipitation between A.D. 575 and the mid-700s, followed by a decline until about A.D. 1005 based on his ratios of spruce-to-pine pollen at Beef Pasture (Petersen 1988:Figure 55). The hydrological curve from Black Mesa, northeast Arizona (Euler et al. 1979:Figure 4) and the arboreal pollen indices from Navajo Reservoir, southwest Colorado and the Chuska Valley, northwest New Mexico (Schoenwetter 1970:Figure 1) document winter precipitation lows around A.D. 600 and from A.D. 700 to 1000. These three studies also document an increase in winter precipitation from A.D. 1000 to A.D. 1200, with a winter precipitation low centered on the mid-1100s and a decline in winter precipitation after A.D. 1200. Using tree-ring records, Dean and Van West (2002:87) identified prolonged droughts in annual or summer precipitation centered on A.D. 1000, the late 1000s, the mid-1100s, late 1200s, and the mid-1400s that likely correspond with dips in the winter precipitation curve presented here (Figure 19). They identified further periods of high annual precipitation in the mid-1000s, the early 1100s, the late 1100s and the early 1300s (Dean and Van West 2002:87) that correspond with slight peaks in the winter precipitation curve presented here (Figure 19).

Petersen’s (1988:Figure 51) pollen ratios also support my inference for a period of low winter precipitation until the mid-1400s, at which time winter precipitation increased and remained high until about A.D. 1600. His ratios also document a period of low winter precipitation from A.D. 1600 to the mid-1800s with short periods of winter precipitation increase centered on the late-1700s and late-1800s, which led him to interpret the Little Ice Age as being relatively dry (Petersen 1994).

Summer Precipitation

Since the zone-based analysis obscures several changes in the pinyon pine pollen influx rates, I refer to Figure 20 when describing summer precipitation fluctuations here and in Table 12. Based on influx rates, I interpret the period prior to A.D. 700 as having a relatively low but moderate amount of summer precipitation. Summer precipitation amounts increased considerably from A.D. 701 – 780, and this was followed by a period of relatively low summer precipitation until A.D. 1180. This period of low summer precipitation, however, was interrupted by extreme lows in the mid-900s and the entire eleventh-century and a short increase in the early 1100s. The effects of the well-known drought in the mid-1100s are represented by a period of slightly reduced pinyon pine pollen influx between A.D. 1120 and 1180 (Figure 20). From A.D. 1180 to A.D. 1490, the pinyon pine pollen influx rates tend to increase, however, this increase was perturbed by short periods of reduced summer precipitation centered on the mid-to-late thirteenth century and the late fourteenth century. This thirteenth-century reduction corresponds to the Great Drought (Douglass 1929). As the pinyon pollen influx rates suggest, however, this drought was not as severe as that of the mid-twelfth century, which is also suggested by tree-ring records (Benson et al. 2006).

After A.D. 1490, the Mesa Verde region experienced a reduction in summer precipitation until about A.D. 1750, at which time summer precipitation increased and continued to be relatively high until the twentieth century. The pinyon pine pollen influx rates, however, suggest that these two low-frequency fluctuations were interrupted by numerous and variable higher frequency fluctuations, with highs occurring in the late 1500s, the late 1600s, the mid 1700s, the early 1800s and the early 1900s and lows occurring in the early 1600s and the late 1700s.

In agreement with my results, Petersen (1988:Figure 51) observed a relatively low pinyon pine pollen influx rate until approximately A.D. 700. His data also document an increase in summer precipitation from A.D. 700 to A.D. 1100, with lows occurring in the mid-900s and the 1000s and a high in the early 1100s. Petersen's results, however, do not document the extensive variability in summer precipitation patterns from A.D. 1181 to 1850 observed in my results (Figure 20). As a result, he interpreted this period as one of consistently low summer precipitation. While this is the long-term trend, my results suggest a high level of variation during this period. In fact, Ahlstrom et al. (1995) suggest that summer precipitation was extremely variable and unpredictable from A.D. 1250 to 1450 in the northern Southwest. The Great Drought of the late thirteenth century was likely initiated by a period of weakening in the summer monsoons (Petersen 1988:94), which may be associated with extremely negative values for the Pacific Decadal Oscillation (PDO) (Benson et al. 2006), and this weakened pattern of summer monsoons may have persisted until the mid-fifteenth century.

Using various tree-ring records from the northern Southwest, Benson et al. (2006:Figure 4) identify droughts centered around A.D. 1090, A.D. 1150 and A.D. 1280 that likely reverberated across the entire Four Corners region. These tree-ring-based climatic reconstructions support my inferences of summer droughts in the A.D. 1000s, the mid-1100s and the late 1200s. Using a Douglas-fir tree-ring record from the Mesa Verde region, Dean and Van West (2002:87) also identified three prolonged droughts in the 1000s, and one in the late 1300s that may correspond with the low-frequency pinyon pine pollen signals for droughts at these times. Their results also pinpointed prolonged droughts in the late 900s, the mid-1300s and the mid-1400s that are expressed well in the Beef Pasture record (Figure 20). Since their drought reconstructions are based on annual precipitation measures, these may have been the result of combined reductions in winter and summer precipitation. The droughts of the late-1200s and the mid-1400s correspond with my inferences of reduced winter precipitation at these times, and since these droughts are poorly expressed in the summer precipitation record here, they may have been driven largely by winter droughts. Dean and Van West (2002:87) also identified prolonged wet periods occurring in the early 1100s, the late 1100s and early 1300s; these wet periods are evidenced here by peaks in the pinyon pine pollen influx rates at these times (Figure 20). Although they also identified a prolonged wet period in the mid-to-late 1000s that is not witnessed in the pinyon pollen data, this wet period does correspond with a peak in winter precipitation at this time, suggesting that this wet period may have been driven largely by increased winter precipitation.

Since my results correspond well to other low- and high-frequency paleoclimatic reconstructions from the northern Southwest, I believe that they accurately reflect the paleoclimate of the Mesa Verde region over the past 2,100 years. I argue further that Figures 17, 19 and 20 serve as appropriate visual reconstructions of low-frequency oscillations in annual temperature, winter precipitation and summer precipitation respectively. The magnitudes of the various climatic fluctuations, however, may not be accurately expressed in these figures.

Climatic Influences on Agricultural Paleoproductivity in the Mesa Verde Region

Since adequate amounts of winter and summer precipitation are necessary for successful agricultural productivity in the Greater Southwest, and since lengthy growing seasons are critical to maize farming in the Mesa Verde region, fluctuations in these variables likely affected the ability of prehistoric (and historic) farmers in this region to successfully dry farm. However, as paleoproductivity modeling based on tree rings seems to suggest (Axtell et al. 2002; Dean et al. 2000; Kohler et al. 2007; Van West 1994), certain areas of the northern Southwest would have always been agriculturally productive regardless of the reconstructed climatic changes.

While the low-frequency temperature reconstruction here will likely augment the results of future paleoproductivity models, climate change cannot explain cultural change *per se* because we need to consider pertinent social variables, such as the mode of production of prehistoric peoples in relation to climate change (e.g., Bettinger 1999:69-70). Further, environmental change can affect social relations and ideological aspects of prehistoric peoples that are linked to resource availability and predictability. Changes in the existing social relations or ideology can make other communities and regions more attractive residential locales, and these sociocultural push and pull factors may encourage people to either enter or leave their existing communities (Benson et al. 2006; see also Dean et al. 2000; Larson et al. 1996). In fact, Ahlstrom et al. (1995) and Lipe (1995:163) argue that the depopulation of the Mesa Verde region in the thirteenth century likely had an ideological component, which they suggest may have been related to the weakening of the summer monsoons at this time.

Regardless of how cultural and demographic changes are mediated, alterations in the subsistence potential of a region can make places more or less desirable areas for dry farming. Dean et al. (1985) suggest that demographic processes observable in the archaeological record, such as population increases, migrations, depopulations, and demic diffusions, respond more closely to low-frequency than to high-frequency environmental changes. Rapid demographic changes occur in response to high-frequency environmental change only when regional carrying capacities are severely reduced due to population growth and/or low-frequency environmental change. Using this model as a basis for the demographic transitions in the Mesa Verde region, Schlanger (1988) hypothesizes that long periods of favorable and stable climate would encourage population maintenance or increase while an instable and unfavorable climate would stimulate out-migration if conditions at the intended destinations appeared to be more favorable.

While Dean et al.'s (1985) proposition is only a model, and deviations from it have been witnessed in the archaeological record of the northern Southwest (e.g., Orcutt 1991), it does suggest that the interrelationships between high- and low-frequency environmental processes on subsistence potential are rather complex, and that understanding both processes in tandem provides a more comprehensive picture of how environmental change affected the paleoproductivity of the Mesa Verde region. Given that paleodemographic estimates for the central Mesa Verde region are temporally well defined, coupling what is already known of the high-frequency processes with the new low-frequency data presented in this thesis should help elucidate the nature of the ecological niche constructed by local agriculturalists. This composite picture will help us to better understand the co-evolution of regional societal structures and environments, which are two of the ultimate aims of the Village Project (Kohler et al. 2007).

The following discussion highlights significant demographic changes in the Mesa Verde region in relation to the low-frequency climate changes presented in this thesis that likely affected agricultural paleoproductivity. Inferences drawn from these comparisons, however, should be considered tentative because the low-frequency paleoclimate data analyzed in this study have yet to be incorporated into the Village Project's paleoproductivity model. Likewise, considering that many more variables are considered in the Village Project's paleoproductivity model, direct correlations between low-frequency climatic fluctuations and changes in agricultural yield estimates should not be expected. Figure 21 isolates and summarizes the reconstructed climate variables from B.C. 100 to A.D. 1400, the period when agricultural practices appeared in the northern Southwest and when a farming way of life became the normative subsistence strategy prior to regional depopulation.

As many researchers contend (Diehl 1997; Hard 1990; Matson 1991, 2002; Wills 1988, 1996), the introduction of domesticates into southwestern diets probably served as some sort of dietary “insurance policy” (Lipe 1999:130), where hunter/gatherer groups used maize to buffer against wild resource scarcity. The earliest dates for agriculture in the northern San Juan region and at higher elevations across the central portion of the Colorado Plateau cluster around 300 B.C. (Geib and Spurr 2000; Lister 1997; Smiley 1994; Stiger and Larson 1992; see also Geib and Spurr 2002), however, this predates the paleoclimatic reconstruction here. Although maize was present in the northern San Juan region, reliance on domesticates was relatively limited until the late Basketmaker II period (A.D. 200 – A.D. 500; Kidder 1927), when successful upland dry farming began to occur (Matson 1991; Lipe 1999; see also Smiley 1994) and when a farming way of life came to the central Mesa Verde region.

Whether the sudden increase in dietary reliance on maize occurring in the late Basketmaker II period in the northern southwest is the result of cultural transmission of agricultural practices to indigenous groups (Irwin Williams 1973), demic diffusion of southern agricultural groups into the region (Matson 1991, 2002), introduction of a different genetic strain of maize, or a combination of these three processes remains contested (Wright 2006). The paleoclimatic reconstruction presented here documents a warming trend that began in the A.D. 200s (Figure 21) and corresponds temporally to this increased reliance on maize. This warming trend likely increased the growing season in the northern San Juan region, which would have increased agricultural success and crop predictability at this time. This warming episode may have encouraged a larger investment in agricultural production as well as an influx of farmers

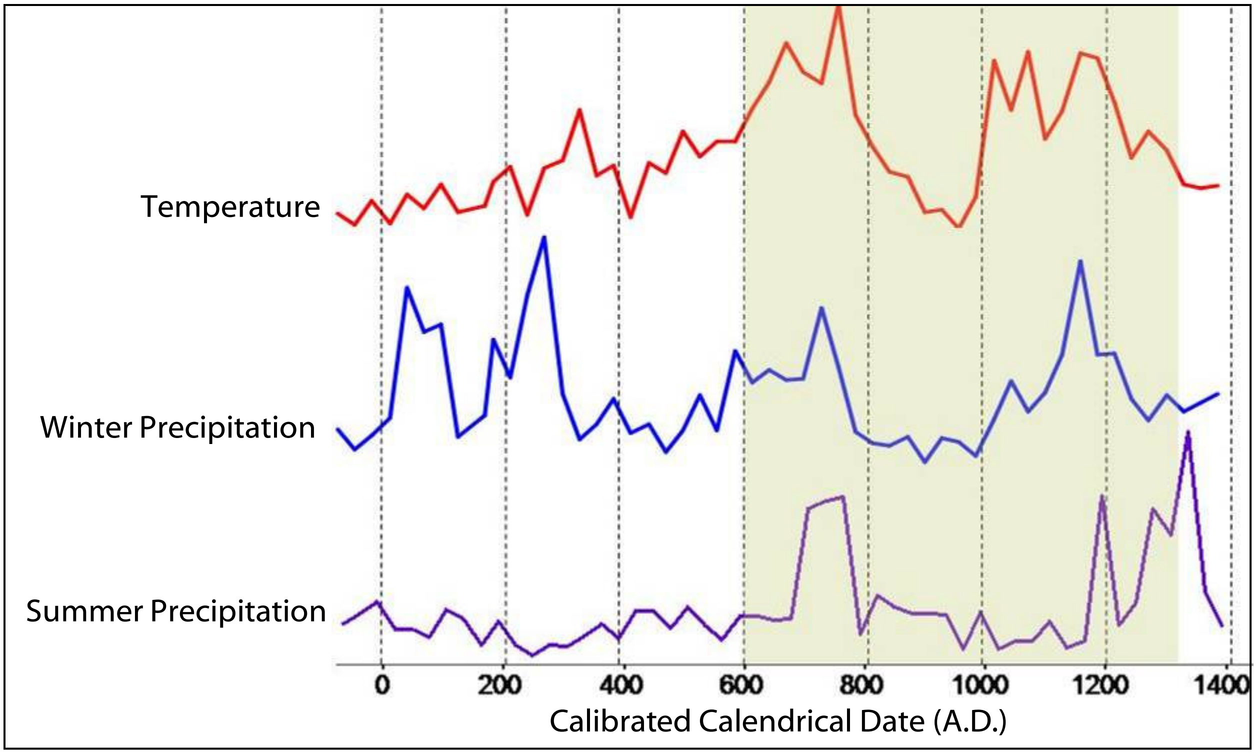

Figure 21. Low-frequency paleoclimate reconstruction from 100 B.C. - A.D. 1400. The temperature curve is derived from the ponderosa pine-to-spruce pollen ratio (Figure 17); the winter precipitation curve is derived from the sedge-to-Cheno/Am pollen ratio (Figure 19); the summer precipitation curve is derived from pinyon pine pollen influx rates (Figure 20). The shaded area represents the 700 year period of occupation in the central Mesa Verde region.

into the northern Southwest. Reductions in winter precipitation after A.D. 290 (Figure 21; Table 12) and a cold period around A.D. 400 (Figure 21), however, may have curtailed the spread of agricultural production to the north and into higher elevations like the central Mesa Verde region. This factor may be related to reluctance of regional agriculturalists to become dependent upon agricultural subsistence until the seventh century. In fact, the central Mesa Verde region, an area near the latitudinal and elevational limit of the Puebloan cultural distribution, was not utilized by agriculturalists until around A.D. 600.

After A.D. 600, populations in the northern San Juan region became more sedentary and reliant on agriculture, as evidenced by an increased investment in residential architecture and

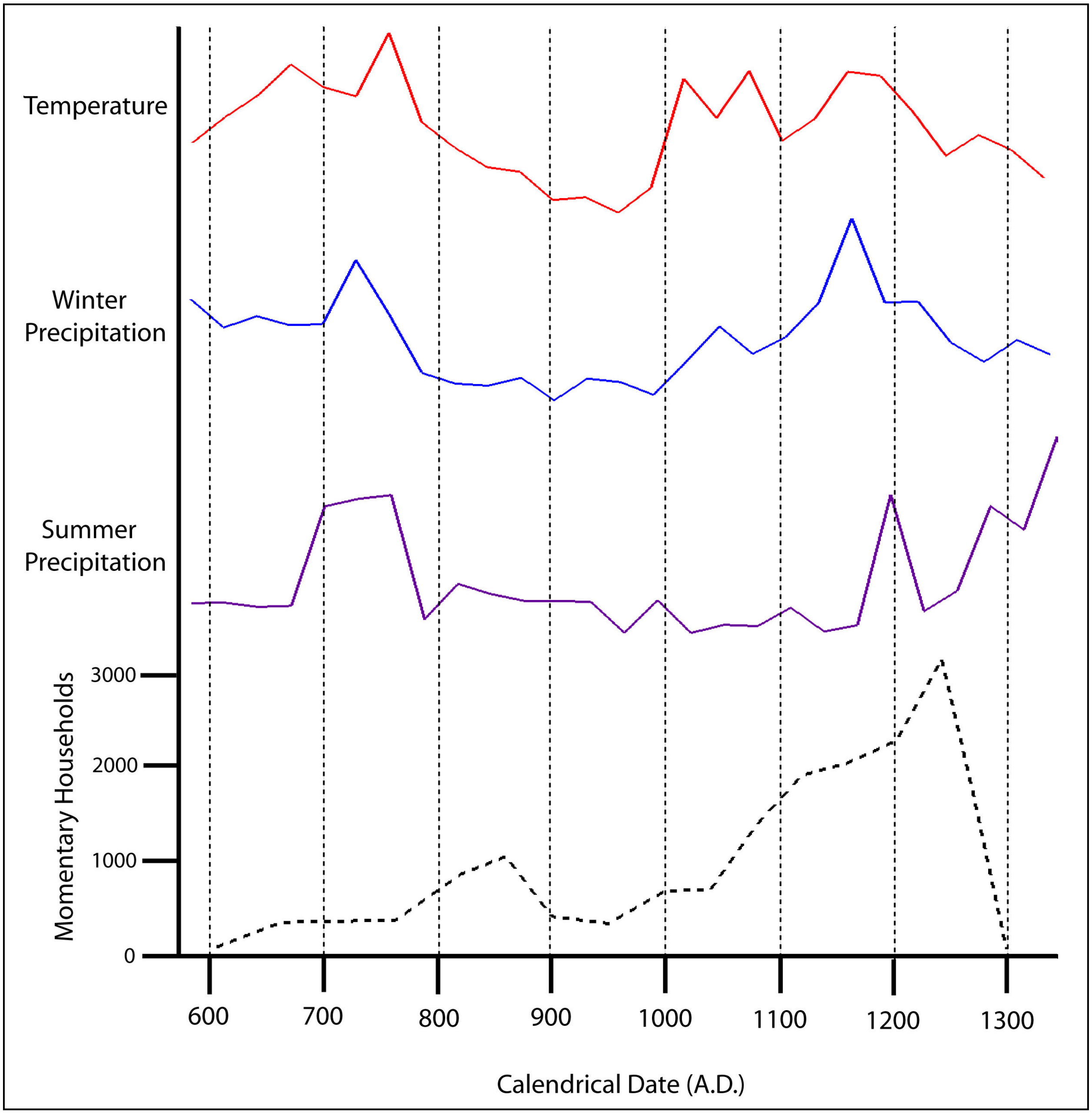

Figure 22. Comparison of low-frequency paleoclimatic conditions to the number of momentary households in the central Mesa Verde region. These momentary household estimates are from the midpoints of the 14 periods observed in the Village Project's paleodemographic reconstruction (Kohler et al. 2006:Table 1).

more maize in the diets. Likewise, this is the approximate period when farmers began to inhabit the central Mesa Verde region. Figure 22 compares the Village Project's population estimates for the central Mesa Verde region (Kohler et al. 2006:Table 1) in relation to the low-frequency paleoclimatic conditions reconstructed here. As it shows, the influx of farmers around A.D. 600 coincides with a notable increase in temperature and a high level of winter precipitation (Figure 22; Tables 10 and 11). These climatic conditions would have favored agricultural productivity, perhaps more so then than at any other time during regional occupation. Around A.D. 780, however, winter precipitation, summer precipitation and regional temperatures appear to have decreased substantially (Figures 22; Tables 10 - 12). Farmers developed new technologies for water management, such as water storage features and runoff irrigation (Schlanger 1988:789), at this time, which may have been an attempt to buffer against these precipitation shortfalls.

There is also a noticeable increase in population in the central Mesa Verde region after A.D. 780 (Figure 22). If the central Mesa Verde region does contain the most productive agricultural land in the northern San Juan region, as Varien (1999; Varien et al. 2000) has argued, this population increase may be the result of dispersed farmers across the northern San Juan region moving into the central Mesa Verde region to access reliable farmland. This period of aggregation and population increase in the Dolores area of the central Mesa Verde region likely affected the environmental and social conditions of the region. Perhaps this increase in population and the reduction in precipitation around A.D. 780 (Figure 22) affected the amount of available farmland to the point where people began to explore alternative farming strategies, such as the water control features identified by Schlanger (1988), to maintain adequate levels of agricultural yields. In fact, the first appearance of field houses in the central Mesa Verde region occurs in the mid-800s (Kohler 1992a), which Kohler (1992a:626-630) suggests reflects a change in local land tenure systems that may have involved increases in social inequality (see also Kane 1989; Schachner 2001:183). Likewise, population increases in the Dolores River area in conjunction with poor climatic conditions may have contributed to changes in the social relations among people, as Schachner (2001) has suggested based on transformations in ritual architecture and practices at this time.

The 200-year duration (A.D. 780 – 980) of low temperatures and precipitation (Figure 22), which are critical climatic variables for reliable maize productivity, may have stressed regional agricultural systems to the point that the vast majority of residents vacated the Dolores River area (Varien 1999; Wilshusen 1995, 1999a) and areas of southeast Utah (Matson et al. 1988; Wilshusen and Ortman 1999) through the ninth and early tenth centuries. While a small number of farmers remained in the central Mesa Verde region (Figure 22), many farmers probably moved southward into northwestern New Mexico (Wilshusen and Ortman 1999; see also Wilshusen and Wilson 1995, Wilshusen 1999b) with no intent to return (Schlanger and Wilshusen 1993:97).

People apparently resettled some of the previously depopulated areas of the northern San Juan region in the late 900s (Duff and Wilshusen 2000; Varien 1999), and many of these settlers were possibly previously displaced farmers and their kin returning to their ancestral homelands. As Figure 22 demonstrates, the climate of the northern San Juan region during the late 900s became increasingly favorable for maize agriculture through increased growing seasons and higher amounts of winter precipitation. The central Mesa Verde region also experienced a return to increasing population levels at this time. This suggests that increased population levels across the northern San Juan region cannot be explained by remnant farmers in the Dolores River area dispersing across the landscape, but that the northern San Juan region was experiencing an overall influx of farmers, likely originating from the south, during this period of favorable climate.

Increasing population levels across the northern San Juan region persisted throughout the eleventh century, including a repopulation of the Cedar Mesa area (Matson et al. 1988) and continued population growth in the central Mesa Verde region (Figure 22) and probably in other areas of the northern San Juan region (Varien 1999; Wilshusen 2002:Figure 5.4). These population increases correspond with continued increases in winter precipitation and temperature, which likely increased agricultural productivity throughout the region; however, summer precipitation remained relatively low during this period (Figure 22; Table 12) as did the overall population level of the northern San Juan region (Duff and Wilshusen 2000). Duff and Wilshusen (2000) and Varien (1999) observe a slight population reduction in the northern San Juan region centered on A.D. 1070, however, this demographic shift does not appear to have occurred in the central Mesa Verde region (Figure 22). If this population reduction was somehow related to climatic change, it may have been in response to reductions in winter precipitation and temperature at the end of the eleventh century (Figure 22). If so, some of these displaced farmers may have aggregated into established communities in the central Mesa Verde region once again (Varien 1999), as evidenced by continuous population growth in this region.

Another population reduction across the northern San Juan region occurred around A.D. 1150 (Duff and Wilshusen 2000; Varien 1999), however, this too was not experienced in the central Mesa Verde region where populations continued to increase throughout the twelfth century (Figure 22). Unlike the population reduction around A.D. 1070, this population reduction corresponds with a well known summer precipitation low in the mid-1100s (Figure 22); this drought is often invoked as a causal force for the collapse of the Chacoan system further south (e.g., Benson et al. 2006). Other climatic variables in the central Mesa Verde region, however, seem relatively favorable for agricultural productivity at this time. Since population levels in the central Mesa Verde region continued to increase in spite of more regional population reductions, it is quite possible that these farmers were once again moving into the central Mesa Verde region, and elsewhere, in search of more favorable agricultural land.

Unlike the Pueblo I period (A.D. 700 – 950), population fluctuations in the northern San Juan region from A.D. 1000 to the mid-1100s do not correspond well with low-frequency climatic changes. Primarily, the low temperatures and winter precipitation during the late eleventh to mid-twelfth centuries (Figure 22) do not seem to have affected the paleodemography of the northern San Juan region or the more localized central Mesa Verde region to any significant extent. Further, although the broad regional population reductions around A.D. 1070 and 1150, as discussed previously, do correspond with slight changes in regional paleoclimates, these climatic changes do not appear to have been as severe as those during the ninth and tenth centuries. Their effects on regional agricultural paleoproductivity, therefore, seem relatively minor.

Applying microeconomic theory and utility functions, Kohler and Van West (1996) predict that periods of high agricultural productivity would stimulate the pooling of resources and sharing among farmers the central Mesa Verde region, resulting in cooperation and population aggregation. Conversely, they predict that periods of low agricultural productivity would stimulate farmers to share less or even defect from their communities and disperse across the landscape. If their predictions accurately model normative behavior, then why were farmers aggregating into community centers in central Mesa Verde region (Varien 1999), thus increasing regional population levels (Figure 22), during the relatively poor climate during the late tenth and eleventh centuries instead of taking up residence in dispersed settlements around these community centers?

One explanation is that there may have been social incentives for people to aggregate into community centers during the eleventh and twelfth centuries. This is the time period when the Chaco regional system was at its apex, and the communities in the central Mesa Verde region were likely participants in this system as evidenced by the presence of Great House architecture and a settlement pattern consisting of ‘small bumps’ around ‘big bumps’ (Lekson 1991). Although the relationships between Mesa Verde communities and those at Chaco Canyon, New Mexico are poorly understood (e.g., Cameron 2005), the social value of participating in such a system may have out-weighed the economic value gained by defection and dispersion. Lightfoot (1984) suggests that places of perceived political, ideological, or social importance, perhaps evidenced in the central Mesa Verde region by Great Houses, Great Kivas, or persistent communities (Varien 1999), may have been attractive enough locations to encourage immigration in the pre-Hispanic southwest. Likewise, Lipe (2002) suggests that leaders situated in Mesa Verde community centers may have been attempting to recruit members, possibly for personal benefit. Interestingly, Kohler et al. (2006) note that this period of Chaco fluorescence in the Mesa Verde region coincides with a period when the normative relationship between population and warfare is inverted, a phenomenon that they suggest was also related to the influence of the Chacoan system. Implying a period of relatively peaceful social relations and cultural fluorescence, Lekson (1999) refers to the northern Southwest as ‘Pax Chaco’ during Chacoan times (A.D. 900 – 1150).

Since the low-frequency climatic regime from the eleventh to mid-twelfth centuries was relatively constant when compared to other periods (Figure 22), it is also possible that the paleodemographic patterns of the northern San Juan region were responding more closely to high-frequency climatic changes during this period. Regional carrying capacities may have been relatively low at this time due to population pressure (Dean et al. 1985) or to human induced environmental changes, such as deforestation or resource depletion (Kohler 1992a, 1992b; Kohler and Matthews 1988). Population levels, however, were not as high as they were in subsequent periods, suggesting that if the carrying capacity was extremely low, it was likely not a result of population pressure at this time.

After A.D. 1170, population levels across the northern San Juan region began to increase once more (Dean et al. 1994; Wilshusen 2002:Figure 5.4), and households became closely aggregated within communities and communities became increasingly aggregated across the landscape (Adler 1990; Varien 1999). While this regionally broad population increase was also occurring in the central Mesa Verde region (Kohler et al. 2006:Table 1), this area experienced its most rapid population increase in the early thirteenth century (Figure 22). Increases in population and settlement aggregation throughout portions of the northern San Juan region, but perhaps not the entire region (see Duff and Wilshusen 2000), continued until the mid-thirteenth century, at which time people had begun a rather rapid out-migration of the region until it was fully depopulated by A.D. 1300 (Dean et al. 1994; Duff and Wilshusen 2000; Kohler et al. 2006; Lipe 1995, 2002; Varien 1999; Wilshusen 2002). This regional depopulation has traditionally been associated with the Great Drought (e.g., Douglass 1929; Hewett 1908; Kidder 1924), however, Van West's (1994) paleoproductivity model for the central Mesa Verde region suggests that productivity would have been high enough to support some continued habitation of the region. As discussed in Chapter 1, however, Van West did not fully address the potential effects of shortened growing seasons on agricultural productivity. Moreover, Van West's paleoproductivity model assumed yields similar to those from maize planted locally in the 1930s and 40s, which may be inappropriate given the differences in technology and the genetic strains of corn being cultivated. I expect that once these new low-frequency data are incorporated into the Village Project's paleoproductivity model, estimates of maize yields/household/year will be considerably lower than those derived from Van West's model.

The low-frequency paleoclimatic reconstruction presented here suggests that by the mid-1200s the Mesa Verde region was experiencing shorter growing seasons due to cooler temperatures and a reduction in winter precipitation (Figure 22; Tables 10 and 11). While the Great Drought is poorly expressed in the pollen record, it did in fact occur, and this phenomenon in combination with winter precipitation deficiencies likely exacerbated the temperature-induced subsistence stress experienced by regional farmer at the end of the thirteenth century. Researchers have often attempted to identify a single climatic cause for the Mesa Verde depopulation at this time, however, the picture presented here suggests that a combination of low temperatures with both winter and summer droughts during the later half of the thirteenth century would have been detrimental to crop productivity throughout the majority of the northern San Juan region, including the central Mesa Verde region. From the data presented here, it appears that the thirteenth century in the central Mesa Verde region may have been one of the worst times for prehistoric agriculturalists in the central Mesa Verde region throughout their 700-year span of occupation.

CHAPTER SEVEN

CONCLUSIONS

In this thesis I have outlined the methods and analyses employed to derive a paleoclimatic reconstruction for the central Mesa Verde region that will be used in the Village Project's (Johnson et al. 2005; Kohler and Carr 1997; Kohler et al. 2000, 2007; Varien et al. 2007) paleoproductivity model. This model calculates maize estimates for the central Mesa Verde region from A.D. 600 to 1300 in relation to a number of factors, including but not limited to high- and low-frequency climatic processes, momentary population estimates, the mode of production, and the nature of resource distribution. As a multidisciplinary study, the results of this thesis are pertinent to both paleoecologists/paleoclimatologists focused on subalpine environments and archaeologists working in the northern Southwest.

The intricate pollen analysis of Beef Pasture Core No. 3 has several implications. From a palynological perspective, this analysis consists of the most closely sampled and radiometrically dated pollen core of lacustrine sediments from the past 2,100 years in North America. As a result, the data presented here are of great utility to other paleoecologists and paleoclimatologists working in the Northern Hemisphere for two reasons. First, by closely sampling the pollen core at every other centimeter, I have been able to reconstruct the paleoclimatic regime of the central Mesa Verde region at a temporal scale that is more relevant to the archaeological record than previous studies. While the long-term climatic trends would have been expressed in a more coarsely sampled pollen core, it is the nature and periodicity of climatic fluctuations that I intended to elucidate. This sampling strategy resulted in a paleoclimatic reconstruction that identifies many of the minor climatic oscillations that would have had significant affects on regional agricultural practices but would not be expressed in more coarsely sampled pollen cores.

Second, by applying a regression equation to a suitable number of radiocarbon samples (n = 16), I have been able to associate climatic fluctuations with temporal periods more compatible with those of tree-ring records. Such comparisons provide for better assessments of both low- and high-frequency climatic changes in a region. Likewise, to evaluate the reliability and the accurateness of observed paleoclimatic changes and their magnitudes, each proxy can serve as a ‘calibration’ for the other if such high temporal resolution is available. Although I do not perform such a calibration in this thesis, these new low-frequency data will be calibrated to high-frequency tree-ring records in the Village Project’s paleoproductivity model.

This analysis is also the first attempt to differentiate the climatic causes for the movement of the lower subalpine forest boundary using pollen data from a single coring location. Further, it is the first analysis that utilizes the ratio of sedge-to-Cheno/Am pollen as a proxy for fluctuations in winter precipitation. Through a comparison of my results to other studies using different proxies for low- and high-frequency climatic changes in the northern Southwest, I have been able to verify the climatic inferences that I draw from these novel methods. Given their success and the cross-verification of my results, these new methods provide other palynological paleoclimatologists with additional tools for elucidating past environments and climates, especially climatic processes that are poorly expressed in other proxies (e.g., low-frequency processes) and for periods that pre-date tree-ring records. Further, tree-ring paleoclimatic reconstructions should benefit from comparison to subalpine pollen records, such as the one presented here, because these provide proxies for the differentiation between seasonal precipitation patterns.

From an archaeological perspective, this analysis has helped to identify the climatic regime of the Mesa Verde region over the past 2,100 years. Considering that the Mesa Verde region is at the elevational limit and near the northern-most latitude for which prehistoric agriculture could have been successful, the low-frequency fluctuations in temperature, winter precipitation and summer moisture identified here are critical for understanding the interrelationships between social structures, subsistence and environments over 700 years of continuous occupation. Although low-frequency climate changes cannot *explain* changes in demographic processes, the associated fluctuations in subsistence potential likely reverberated in the social realm, where social relations and ideology influence human action. Since these new paleoclimate data have yet to be incorporated into the Village Project's paleoproductivity model, inferences drawn solely from these data should be considered tentative. Broad correspondence between demography and climate, however, does suggest that changes in agricultural potential and productivity in the central Mesa Verde region were possible impetuses for population movement. The demographic trajectory for the past 2,100 years in the Mesa Verde region corresponds closely to the low-frequency fluctuations in critical climatic variables, with the exception of the A.D. 1000 to 1150 period. Provided that population fluctuations and demographic patterns within this period do not correlate well with predictions based on microeconomic theory, other sociocultural phenomena may have influenced human action on such a large scale more so than subsistence stress.

A farming way of life became the normative pattern for people inhabiting the northern San Juan region around A.D. 600, which corresponds with what appears here to have been a period of high agricultural productivity. A major depopulation of the northern San Juan region, including the highly productive agricultural lands of the central Mesa Verde region, occurred in the A.D. 800s and early 900s during a sharp decline in favorable climatic conditions. These vacating farmers likely found residence south of the Mesa Verde region in areas such as the

Chuska Valley, Totah, and Chaco Canyon regions of northwestern New Mexico, whose lower elevations would have entailed longer growing seasons.

Population in the central Mesa Verde region began to grow once more in the eleventh century and continued until the complete depopulation of the region near the end of the thirteenth century. This period of habitation corresponds to an era of relatively favorable, yet variable, climate conditions that would have supported extensive agricultural practices. Further, the ultimate depopulation did occur during a time of reduced growing seasons and low winter precipitation rates. This suggests that temperature, which was omitted in Van West's (1994) paleoproductivity model, was a crucial climatic variable with which ancient Mesa Verdeans dealt. While the demographic processes witnessed during the 700 years of continuous occupation were possibly in response to changes in agricultural productivity in the Mesa Verde region, a full understanding of the nature of demographic change, however, requires an understanding and assessment of the social structures that mediated human decisions and actions in the prehistoric Mesa Verde landscape.

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APPENDIX A: POLLEN[a] COUNTS AND ESTIMATED DATES FOR EACH SAMPLE

Sample #	surface	1	2	3	4	5	6	7	8	9	10	11
Depth (cm)	0	4-5	6-7	8-9	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25
Estimated date (A.D.)[b]	2000	1929	1900	1871	1843	1814	1785	1757	1728	1700	1671	1642
Biostratigraphic Zone[c]	-	11	11	11	11	11	11	11	11	10	10	10
Lycopodium (tracer)[d]	58	170	129	150	330	200	249	193	189	208	211	256
Abies	1	5	2	5	7	7	3	6	8	4	3	3
Alnus	2	3	0	3	2	1	1	1	1	1	0	2
Apiaceae	0	1	1	0	0	1	1	5	4	0	0	1
Artemesia	21	33	36	49	44	67	37	55	60	75	56	56
Asteraceae, High-spine	3	1	0	5	2	3	1	5	4	4	2	1
Asteraceae, Low-spine	35	25	15	32	32	42	26	37	22	28	27	23
Betula	0	0	0	0	0	0	1	0	0	0	0	0
Carex	118	57	218	143	94	23	113	62	64	197	159	170
Celtis	0	0	0	0	0	0	0	0	0	0	0	0
Cirsium	0	1	0	0	0	0	0	0	0	0	0	0
Cheno/Am	37	23	23	21	50	52	30	44	61	36	43	33
Ephedra torreyana	0	2	1	0	2	0	2	1	0	0	0	0
Ephedra viridis	1	2	2	2	3	1	4	5	2	1	3	3
Fabaceae	0	0	0	0	0	0	0	0	0	0	0	0
Fragaria	0	0	0	0	0	1	0	0	0	0	0	0
Geraniaceae	0	1	0	0	0	0	0	0	0	0	0	0
Juncus	0	0	0	0	0	0	0	0	0	0	0	0
Juniperus	4	1	7	6	3	0	3	4	6	5	4	5
Lamiaceae	0	0	0	0	0	1	0	0	0	0	0	0
Liguliflorae	18	3	1	0	1	0	1	0	0	0	0	0
Lythraceae	0	0	0	0	0	0	0	0	0	0	0	0
Onagraceae	0	0	0	0	0	0	0	0	0	0	0	0
Opuntia	0	1	0	0	0	0	0	0	0	0	0	0
Parthenocissus	0	0	0	0	0	0	0	0	0	0	0	0
Picea engelmannii	11	126	63	71	59	117	104	77	79	37	62	33
Pinaceae bladder, large[e]	6	32	11	22	24	38	39	25	25	16	24	8
Pinaceae bladder, small[e]	14	11	7	4	15	29	15	14	19	11	50	10
Pinus edulis	34	18	20	17	34	43	14	27	16	14	24	17
Pinus ponderosa	64	101	80	108	139	104	125	139	122	97	111	116
Poaceae	77	9	8	13	20	9	7	10	17	23	12	25
Polemoniaceae	0	0	0	0	0	0	0	1	0	0	0	0
Polygala	0	0	0	0	0	0	0	0	0	0	0	0
Populus	1	0	0	0	1	0	0	0	0	0	0	0
Pseudotsuga	0	0	0	0	0	0	1	0	0	0	0	0
Quercus	24	31	34	42	16	16	15	12	11	9	5	8
Ranunculaceae	1	1	0	2	2	0	1	1	1	0	0	1
Rosaceae	3	1	1	3	1	4	0	3	3	1	2	4
Rubus	1	0	0	0	0	0	0	0	0	0	0	0
Salix	6	5	0	2	11	7	11	8	13	9	8	5
Sarcobatus	3	10	3	3	3	0	2	3	1	3	2	2
Thalictrum	2	1	1	1	2	3	2	1	1	4	1	0
Unknown types	1	0	0	0	1	1	0	0	4	1	0	0
Typha	35	75	5	2	2	0	0	0	0	0	0	0
Verbenaceae	0	1	0	0	0	0	0	0	0	0	0	0
Total	523	581	539	556	571	569	559	546	544	576	598	526

[a] see Table 5 for descriptions of each pollen type listed

[b] date for the mid-point of the sample estimated from the weighted least-squares regression of depth on ^{14}C dates (see Figure 14)

[c] zones defined by stratigraphically constrained cluster analysis (see Figure 15)

[d] tracer spores are excluded from pollen sums

[e] each Pinaceae bladder in the tally actually represents two bladders, which combined account for one pollen grain

*pollen anther present (suggests that its associated plant was located very close to the sampling locale)

APPENDIX A: POLLEN[a] COUNTS AND ESTIMATED DATES FOR EACH SAMPLE

Sample #	12	13	14	15	16	17	18	19	20	21	22
Depth (cm)	26-27	28-29	30-31	32-33	34-35	36-37	38-39	40-41	42-43	44-45	46-47
Estimated date (A.D.)[b]	1614	1585	1556	1528	1499	1470	1442	1413	1385	1356	1327
Biostratigraphic Zone[c]	9	9	9	9	9	8	8	8	7	7	7
Lycopodium (tracer)[d]	306	202	285	132	348	344	275	439	607	508	243
Abies	0	1	3	3	4	2	4	4	4	6	6
Alnus	1	1	1	2	0	0	2	2	2	1	0
Apiaceae	0	1	0	2	0	1	0	2	1	1	1
Artemesia	49	36	54	55	35	50	75	72	69	39	34
Asteraceae, High-spine	2	9	5	4	2	5	5	4	2	6	3
Asteraceae, Low-spine	10	10	15	18	15	17	31	17	29	25	16
Betula	0	0	0	0	1	0	0	0	0	0	1
Carex	322	427	297	296	293*	97	80	56	81	123	63
Celtis	0	0	0	0	0	0	0	0	0	0	0
Cirsium	0	0	0	0	0	0	0	1	0	0	0
Cheno/Am	14	14	19	34	14	18	30	47	36	62	36
Ephedra torreyana	0	0	0	0	0	0	0	0	1	1	0
Ephedra viridis	3	0	4	2	0	0	2	1	3	7	2
Fabaceae	0	0	0	0	0	1	0	0	0	0	0
Fragaria	0	0	1	0	1	0	0	1	1	2	0
Geraniaceae	0	0	0	0	0	0	0	0	0	0	0
Juncus	0	0	0	0	0	0	0	0	0	0	0
Juniperus	1	10	5	10	3	4	13	0	2	5	1
Lamiaceae	0	0	0	0	0	0	0	0	0	0	0
Liguliflorae	0	0	0	0	0	0	0	0	0	0	0
Lythraceae	0	0	0	0	0	0	0	0	0	0	0
Onagraceae	0	0	0	0	0	0	1	0	0	0	0
Opuntia	0	0	0	0	0	0	0	0	0	0	0
Parthenocissus	0	0	0	0	0	0	0	0	0	0	0
Picea engelmannii	26	24	42	22	32	27	49	42	95	64	81
Pinaceae bladder, large[e]	7	10	9	9	12	7	6	7	13	16	18
Pinaceae bladder, small[e]	21	14	8	18	6	13	23	38	15	16	18
Pinus edulis	7	12	22	7	21	43	64	44	36	53	77
Pinus ponderosa	45	107	98	109	134	195	165	155	143	94	122
Poaceae	33	30	21	34	13	11	13	18	9	17	10
Polemoniaceae	0	0	0	0	0	0	0	0	0	0	0
Polygala	0	0	0	0	1	0	0	0	0	0	0
Populus	1	0	0	1	0	0	0	1	1	0	1
Pseudotsuga	0	0	0	0	0	0	1	0	0	0	0
Quercus	3	11	6	9	10	8	3	12	6	4	7
Ranunculaceae	3	0	0	1	0	0	1	0	0	0	0
Rosaceae	1	0	0	3	1	3	2	5	6	0	1
Rubus	0	0	0	0	0	0	0	0	0	0	0
Salix	2	6	0	4	3	1	6	8	11	16	5
Sarcobatus	1	1	2	3	4	1	4	3	3	1	0
Thalictrum	6	3	5	4	4	4	4	6	3	7	5
Unknown types	1	2	1	2	4	0	0	0	0	1	1
Typha	0	0	0	0	0	0	0	0	0	0	0
Verbenaceae	0	0	0	0	0	0	0	0	0	0	0
Total	559	729	618	652	613	508	584	546	572	567	509

[a] see Table 5 for descriptions of each pollen type listed

[b] date for the mid-point of the sample estimated from the weighted least-squares regression of depth on ^{14}C dates (see Figure 14)

[c] zones defined by stratigraphically constrained cluster analysis (see Figure 15)

[d] tracer spores are excluded from pollen sums

[e] each Pinaceae bladder in the tally actually represents two bladders, which combined account for one pollen grain

*pollen anther present (suggests that its associated plant was located very close to the sampling locale)

APPENDIX A: POLLEN[a] COUNTS AND ESTIMATED DATES FOR EACH SAMPLE

Sample #	23	24	25	26	27	28	29	30	31	32	33
Depth (cm)	48-49	50-51	52-53	54-55	56-57	58-59	60-61	62-63	64-65	66-67	68-69
Estimated date (A.D.)[b]	1299	1270	1241	1213	1184	1156	1127	1098	1070	1041	1012
Biostratigraphic Zone[c]	7	7	6	6	6	6	6	6	6	6	6
Lycopodium (tracer)[d]	268	229	348	340	225	365	554	514	624	386	484
Abies	2	4	3	3	2	0	2	3	4	3	2
Alnus	0	1	1	1	3	0	1	2	2	1	1
Apiaceae	0	0	1	1	3	1	2	0	2	3	3
Artemesia	44	34	49	58	78	48	62	62	56	68	68
Asteraceae, High-spine	2	3	2	2	3	2	4	7	8	10	4
Asteraceae, Low-spine	23	20	30	29	21*	36	51	36*	34	38	40
Betula	0	0	0	0	0	0	0	0	1	0	0
Carex	70	55	97	151	116	182	116	91	69	78	57
Celtis	0	0	0	0	0	0	0	0	0	0	0
Cirsium	0	0	0	0	0	0	0	0	0	0	0
Cheno/Am	32	36	46	45	35	31	35	40	39	30	37
Ephedra torreyana	2	0	0	1	3	0	0	1	0	1	1
Ephedra viridis	3	2	6	1	1	3	1	0	3	1	3
Fabaceae	0	0	0	1	0	1	0	0	0	0	0
Fragaria	1	1	0	0	1	0	1	1	0	1	0
Geraniaceae	0	0	0	0	0	0	0	0	0	0	0
Juncus	0	0	0	0	0	0	0	0	0	0	0
Juniperus	3	1	1	0	4	5	4	9	3	3	4
Lamiaceae	0	0	0	0	1	0	0	0	0	0	0
Liguliflorae	0	0	0	0	0	0	0	0	0	1	0
Lythraceae	0	0	0	0	0	0	0	0	0	0	0
Onagraceae	0	0	0	0	1	0	0	0	0	0	0
Opuntia	0	0	0	0	0	0	0	0	0	0	0
Parthenocissus	0	0	0	0	0	0	1	0	0	0	0
Picea engelmannii	75	89	76	48	36	40	51	55	48	56	45
Pinaceae bladder, large[e]	19	17	19	20	14	6	9	8	8	12	8
Pinaceae bladder, small[e]	33	38	23	11	15	11	9	14	10	7	9
Pinus edulis	48	49	31	20	52	14	16	33	23	15	13
Pinus ponderosa	146	194	141	122	112	127	124	115	153	137	138
Poaceae	16	5	14	17	23	14	27	21	17	22	36
Polemoniaceae	0	0	0	0	0	0	0	0	0	0	0
Polygala	0	0	0	0	0	0	0	0	0	0	0
Populus	1	0	0	0	0	0	0	1	0	0	0
Pseudotsuga	0	0	1	0	0	0	0	0	0	0	0
Quercus	13	13	9	13	10	12	23	21	24	17	22
Ranunculaceae	0	0	0	1	0	0	0	0	0	0	0
Rosaceae	3	4	0	4	2	1	2	4	1	5	5
Rubus	0	0	0	0	0	0	0	0	0	0	0
Salix	9	1	9*	3	0	5	5	14	17	15	17
Sarcobatus	2	0	3	2	1	1	2	4	2	1	1
Thalictrum	4	6	7	3	10	4	0	8	7	5	4
Unknown types	2	0	1	0	1	1	1	1	7	0	2
Typha	0	0	0	0	0	0	0	0	0	0	0
Verbenaceae	0	0	0	0	0	0	0	0	0	0	0
Total	553	573	570	557	548	545	549	551	538	530	520

[a] see Table 5 for descriptions of each pollen type listed

[b] date for the mid-point of the sample estimated from the weighted least-squares regression of depth on ^{14}C dates (see Figure 14)

[c] zones defined by stratigraphically constrained cluster analysis (see Figure 15)

[d] tracer spores are excluded from pollen sums

[e] each Pinaceae bladder in the tally actually represents two bladders, which combined account for one pollen grain

*pollen anther present (suggests that its associated plant was located very close to the sampling locale)

APPENDIX A: POLLEN[a] COUNTS AND ESTIMATED DATES FOR EACH SAMPLE

Sample #	34	35	36	37	38	39	40	41	42	43	44
Depth (cm)	70-71	72-73	74-75	76-77	78-79	80-81	82-83	84-85	86-87	88-89	90-91
Estimated date (A.D.)[b]	984	955	926	898	869	841	812	783	755	726	697
Biostratigraphic Zone[c]	5	5	5	5	5	5	4	4	4	4	4
Lycopodium (tracer)[d]	226	332	193	283	270	273	242	319	165	138	206
Abies	7	15	27	7	15	3	0	4	2	1	4
Alnus	0	2	0	1	0	0	1	1	2	0	0
Apiaceae	2	1	1	0	1	1	0	0	0	0	0
Artemesia	53	61	44	101	76	61	101	80	46	43	49
Asteraceae, High-spine	8	4	2	2	6	6	4	1	3	3	4
Asteraceae, Low-spine	27	33	18	17	22*	28	22	26	23*	13	16
Betula	0	1	0	0	0	0	0	0	0	0	0
Carex	16	46	47	20	43	38	55	74	104	198	64
Celtis	0	0	0	0	0	0	0	0	0	0	0
Cirsium	0	0	0	0	0	0	0	0	0	0	0
Cheno/Am	30	48	46	54	41	47	63	62	35	43	24
Ephedra torreyana	1	0	1	1	0	1	1	0	0	1	0
Ephedra viridis	3	6	0	3	5	2	2	3	4	0	1
Fabaceae	0	0	0	0	0	0	0	0	0	0	0
Fragaria	1	0	0	0	1	0	0	0	0	1	0
Geraniaceae	0	0	0	0	0	0	0	0	0	0	0
Juncus	0	0	0	0	0	0	0	0	0	0	0
Juniperus	5	4	0	4	2	4	2	3	5	6	2
Lamiaceae	0	0	0	0	0	0	0	0	0	0	0
Liguliflorae	0	0	0	0	0	1	0	0	0	0	0
Lythraceae	0	0	0	0	0	0	0	0	0	0	0
Onagraceae	0	0	0	0	0	0	0	0	0	0	0
Opuntia	0	0	0	0	0	0	0	0	0	0	0
Parthenocissus	0	0	0	0	0	0	0	0	0	0	0
Picea engelmannii	91	118	139	133	98	89	59	68	47	47	73
Pinaceae bladder, large[e]	20	24	24	31	18	10	20	15	17	14	26
Pinaceae bladder, small[e]	12	15	7	21	21	22	29	21	26	13	26
Pinus edulis	17	9	14	21	20	23	24	15	38	31	44
Pinus ponderosa	123	113	167	154	157	149	117	162	178	131	214
Poaceae	23	19	6	11	17	10	10	10	25	18	2
Polemoniaceae	0	0	0	0	0	0	0	0	0	0	0
Polygala	0	0	0	0	0	0	0	0	0	0	0
Populus	2	0	0	0	0	0	0	0	1	0	0
Pseudotsuga	0	0	0	0	0	0	0	0	0	0	0
Quercus	10	13	17	19	26	18	17	17	4	15	6
Ranunculaceae	2	0	0	0	0	0	0	0	0	0	0
Rosaceae	1	4	6	3	4	3	5	3	1	2	1
Rubus	0	0	0	0	0	0	0	0	0	0	0
Salix	69	25	10	5	30	39	13	6	5	11	2
Sarcobatus	2	2	0	2	0	4	2	2	1	0	1
Thalictrum	2	2	1	1	7	5	4	6	1	3	0
Unknown types	6	0	0	1	4	8	2	1	0	1	0
Typha	0	0	0	0	0	0	0	0	0	0	0
Verbenaceae	0	0	0	0	0	0	0	0	0	0	0
Total	533	563	577	612	614	572	553	580	568	595	559

[a] see Table 5 for descriptions of each pollen type listed

[b] date for the mid-point of the sample estimated from the weighted least-squares regression of depth on ^{14}C dates (see Figure 14)

[c] zones defined by stratigraphically constrained cluster analysis (see Figure 15)

[d] tracer spores are excluded from pollen sums

[e] each Pinaceae bladder in the tally actually represents two bladders, which combined account for one pollen grain

*pollen anther present (suggests that its associated plant was located very close to the sampling locale)

APPENDIX A: POLLEN[a] COUNTS AND ESTIMATED DATES FOR EACH SAMPLE

Sample #	45	46	47	48	49	50	51	52	53	54
Depth (cm)	92-93	94-95	96-97	98-99	100-101	102-103	104-105	106-107	108-109	110-111
Estimated date (A.D.)[b]	669	640	612	583	554	526	497	468	440	411
Biostratigraphic Zone[c]	4	4	4	4	3	3	3	3	3	3
Lycopodium (tracer)[d]	224	230	168	155	371	284	260	398	220	268
Abies	0	0	0	4	3	4	5	6	2	2
Alnus	3	0	1	0	1	1	1	0	2	0
Apiaceae	0	0	2	2	1	0	0	3	0	1
Artemesia	109	62	44*	68	55	70	72	63	59	62
Asteraceae, High-spine	5	3	2	4	2	1	5	1	4	0
Asteraceae, Low-spine	35	33	13	19	27*	25	37*	19	25	20
Betula	1	0	0	0	0	1	0	0	0	0
Carex	108	125	123	113	40	62	50	26	35	38
Celtis	0	0	0	0	0	0	1	0	0	0
Cirsium	0	0	0	0	0	0	0	0	0	0
Cheno/Am	41	43	48	33	32	28	40	41	25	33
Ephedra torreyana	0	0	0	0	1	1	0	0	0	0
Ephedra viridis	1	3	9*	1	2	1	2	2	3	1
Fabaceae	0	0	0	0	0	0	0	0	0	0
Fragaria	0	0	1	0	0	1	0	0	0	0
Geraniaceae	0	0	0	0	0	0	0	0	0	0
Juncus	0	0	0	0	0	0	0	0	0	0
Juniperus	7	3	3	4	5	5	3	3	3	6
Lamiaceae	0	0	0	0	0	0	0	0	0	0
Liguliflorae	0	0	0	0	0	0	1	1	0	0
Lythraceae	0	0	0	0	0	0	0	0	1	0
Onagraceae	0	0	0	0	0	0	0	0	0	0
Opuntia	0	0	0	0	0	0	0	0	0	0
Parthenocissus	0	0	0	0	0	0	0	0	0	0
Picea engelmannii	52	60	80	69	97	93	78	110	104	131
Pinaceae bladder, large[e]	12	18	18	19	21	10	12	16	20	15
Pinaceae bladder, small[e]	18	17	24	12	19	12	12	11	23	13
Pinus edulis	15	15	12	11	15	17	22	22	17	21
Pinus ponderosa	171	168	197	142	200	174	170	183	185	143
Poaceae	32	17	14	15	18	17	19	31	32	33
Polemoniaceae	0	0	0	0	0	0	0	0	0	0
0Polygala	0	0	0	0	0	0	0	0	0	0
Populus	0	0	0	0	1	0	0	0	0	0
Pseudotsuga	1	0	0	1	0	0	0	0	0	0
Quercus	9	8	11	14	9	7	9	12	7	14
Ranunculaceae	0	0	0	0	0	0	0	0	0	0
Rosaceae	0	1	2	1	4	2	2	1	0	1
Rubus	0	0	0	0	0	0	0	0	0	0
Salix	4	9	4	2	4	5	3	4	2	4
Sarcobatus	2	3	2	3	0	5	2	3	0	3
Thalictrum	2	6	2	2	1	5	1	3	2	4
Unknown types	4	0	0	0	0	3	0	2	1	0
Typha	0	0	0	0	0	0	0	0	0	0
Verbenaceae	0	0	0	0	0	0	0	0	0	0
Total	632	594	612	539	558	550	547	563	552	545

[a] see Table 5 for descriptions of each pollen type listed

[b] date for the mid-point of the sample estimated from the weighted least-squares regression of depth on ^{14}C dates (see Figure 14)

[c] zones defined by stratigraphically constrained cluster analysis (see Figure 15)

[d] tracer spores are excluded from pollen sums

[e] each Pinaceae bladder in the tally actually represents two bladders, which combined account for one pollen grain

*pollen anther present (suggests that its associated plant was located very close to the sampling locale)

APPENDIX A: POLLEN[a] COUNTS AND ESTIMATED DATES FOR EACH SAMPLE

Sample #	55	56	57	58	59	60	61	62	63
Depth (cm)	112-113	114-115	116-117	118-119	120-121	122-123	124-125	126-127	128-129
Estimated Date (A.D.)[b]	382	354	325	297	268	239	211	182	168
Biostratigraphic Zone[c]	3	3	3	3	2	2	2	2	2
Lycopodium (tracer)[d]	354	399	387	730	804	1047	666	435	522
Abies	1	3	5	5	6	3	6	2	8
Alnus	0	1	1	1	0	0	2	3	2
Apiaceae	0	0	0	0	0	0	0	0	0
Artemesia	85	79	61	51	44	38	49	54	60
Asteraceae, High-spine	1	4	2	5	2	1	5	1	3
Asteraceae, Low-spine	35	24	22	21	14	7	15	16	18
Betula	0	1	0	0	0	0	0	0	0
Carex	75	48	32	54	111	104	70	101	74
Celtis	0	0	0	0	0	0	0	0	0
Cirsium	0	0	0	0	0	0	0	0	0
Cheno/Am	36	34	32	24	17	21	26	27	45
Ephedra torreyana	0	1	0	1	1	1	0	2	0
Ephedra viridis	3	3	3	1	4	2	2	1	2
Fabaceae	0	0	0	0	0	0	0	0	0
Fragaria	0	0	0	0	0	0	0	0	0
Geraniaceae	0	0	0	0	0	0	0	0	0
Juncus	0	0	0	0	1	0	0	0	0
Juniperus	3	11	1	5	6	2	4	3	3
Lamiaceae	0	0	0	0	0	0	0	0	0
Liguliflorae	0	2	0	1	0	1	0	0	0
Lythraceae	0	0	0	0	0	0	0	0	0
Onagraceae	0	0	1	0	0	0	0	0	0
Opuntia	0	0	0	0	0	0	0	0	0
Parthenocissus	0	0	0	0	0	0	0	0	0
Picea engelmannii	80	86	72	89	87	130	103	87	105
Pinaceae bladder, large[e]	24	19	10	19	11	8	14	18	25
Pinaceae bladder, small[e]	16	9	15	18	13	6	7	9	12
Pinus edulis	15	24	18	23	26	20	21	28	17
Pinus ponderosa	140	140	176	161	149	147	178	134	130
Poaceae	36	54	48	45	26	27	32	28	24
Polemoniaceae	0	0	0	0	0	0	0	0	0
Polygala	0	0	0	0	0	0	0	0	0
Populus	0	0	0	0	0	0	0	0	1
Pseudotsuga	1	1	0	0	0	0	0	1	0
Quercus	19	11*	14	14	14	7	6	6	8
Ranunculaceae	0	0	0	0	0	0	0	0	0
Rosaceae	3	1	3	2	2	1	1	0	2
Rubus	0	0	0	0	0	0	0	0	0
Salix	1	5	4	5	1	3	3*	3	0
Sarcobatus	3	3	2	4	2	0	0	4	1
Thalictrum	1	4	4	8	2	3	2	6	3
Unknown types	1	1	1	1	2	0	3	1	0
Typha	0	0	0	0	0	0	0	0	0
Verbenaceae	0	0	0	0	0	0	0	0	0
Total	579	569	527	558	541	532	549	535	543

[a] see Table 5 for descriptions of each pollen type listed

[b] date for the mid-point of the sample estimated from the weighted least-squares regression of depth on ^{14}C dates (see Figure 14)

[c] zones defined by stratigraphically constrained cluster analysis (see Figure 15)

[d] tracer spores are excluded from pollen sums

[e] each Pinaceae bladder in the tally actually represents two bladders, which combined account for one pollen grain

*pollen anther present (suggests that its associated plant was located very close to the sampling locale)

APPENDIX A: POLLEN[a] COUNTS AND ESTIMATED DATES FOR EACH SAMPLE

Sample #	64	65	66	67	68	69	70	71
Depth (cm)	130-131	132-133	134-135	136-137	138-139	140-141	142-143	144-145
Estimated date (A.D.)[b]	125	96	68	39	10	-18	-47	-76
Biostratigraphic Zone[c]	2	2	2	2	1	1	1	1
Lycopodium (tracer)[d]	458	238	337	373	431	306	327	345
Abies	11	7	3	4	8	9	7	5
Alnus	1	0	1	2	0	0	0	1
Apiaceae	0	0	0	1	0	0	0	1
Artemesia	48	52	45	45	51	29	43	36
Asteraceae, High-spine	2	2	1	1	2	0	3	0
Asteraceae, Low-spine	20	20	28	27	22	18	19	25
Betula	0	0	0	0	0	0	1	0
Carex	43	116	142	144	76	35	29	47*
Celtis	0	0	0	0	0	0	0	0
Cirsium	0	0	0	0	0	0	0	0
Cheno/Am	41	28	36	28	48	32	41	37
Ephedra torreyana	1	1	0	1	0	0	0	1
Ephedra viridis	2	2	1	2	2	2	5	2
Fabaceae	0	0	0	0	0	0	0	0
Fragaria	0	0	0	0	0	0	0	0
Geraniaceae	0	0	0	0	0	0	0	0
Juncus	0	0	0	0	0	0	0	0
Juniperus	4	2	4	5	4	2	1	4
Lamiaceae	0	0	0	0	0	0	0	0
Liguliflorae	0	0	0	0	0	0	0	0
Lythraceae	0	1	0	0	0	0	0	0
Onagraceae	1	0	0	0	0	0	0	0
Opuntia	0	0	0	0	0	0	0	0
Parthenocissus	0	0	0	0	0	0	0	0
Picea engelmannii	127	96	103	103	133	146	166	136
Pinaceae bladder, large[e]	54	27	18	27	30	53	25	24
Pinaceae bladder, small[e]	15	12	9	12	13	14	6	11
Pinus edulis	31	19	15	20	23	28	24	21
Pinus ponderosa	147	145	125	143	135	190	166	156
Poaceae	28	8	14	15	18	13	15	25
Polemoniaceae	0	0	0	0	0	0	0	0
Polygala	0	0	0	0	0	0	0	0
Populus	0	0	0	0	0	0	0	0
Pseudotsuga	0	0	0	0	0	0	0	0
Quercus	11*	10	5	14	5	8	12	13
Ranunculaceae	0	0	0	0	1	0	0	0
Rosaceae	0	2	2	1	0	1	1	1
Rubus	0	0	0	0	0	0	0	0
Salix	2	1	2	0	1	0	0	2
Sarcobatus	1	3	0	2	0	2	1	1
Thalictrum	1	7	3	2	1	2	0	3
Unknown types	1	3	0	0	2	0	0	0
Typha	0	0	0	0	0	0	0	0
Verbenaceae	0	0	0	0	0	0	0	0
Total	592	564	557	599	575	584	566	552

[a] see Table 5 for descriptions of each pollen type listed

[b] date for the mid-point of the sample estimated from the weighted least-squares regression of depth on ^{14}C dates (see Figure 14)

[c] zones defined by stratigraphically constrained cluster analysis (see Figure 15)

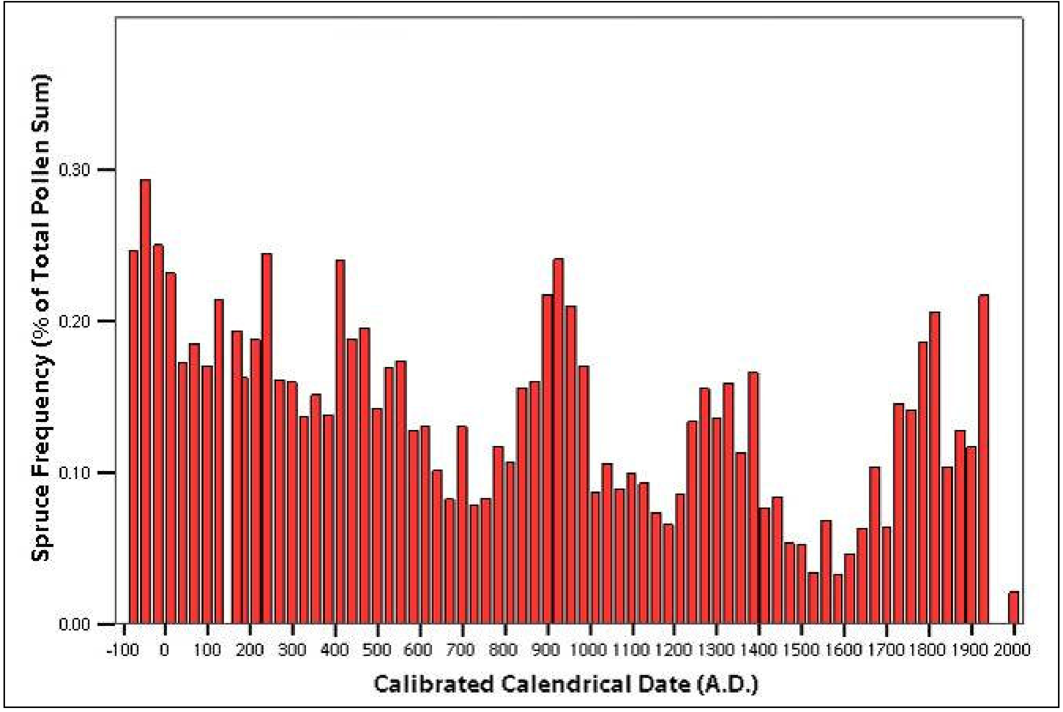
[d] tracer spores are excluded from pollen sums

[e] each Pinaceae bladder in the tally actually represents two bladders, which combined account for one pollen grain

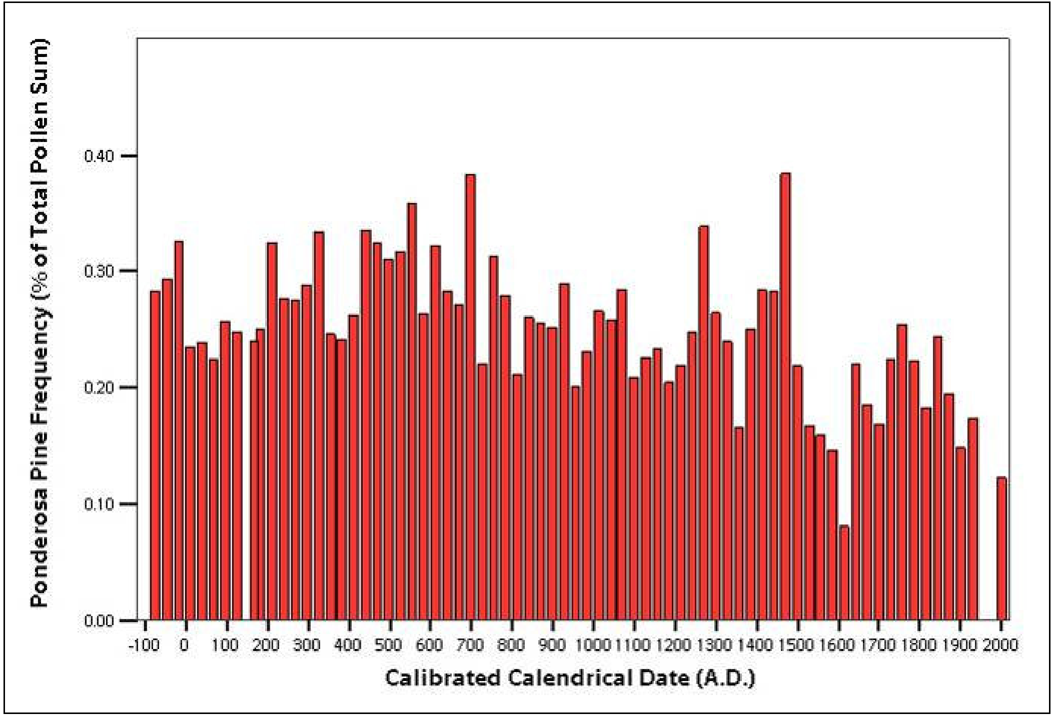
*pollen anther present (suggests that its associated plant was located very close to the sampling locale)

APPENDIX B: BARCHARTS OF THE POLLEN PERCENTAGES AND INFLUX RATES FOR EACH INDICATOR TAXON

Percentages of spruce pollen in each sample plotted by the estimated calendrical date.

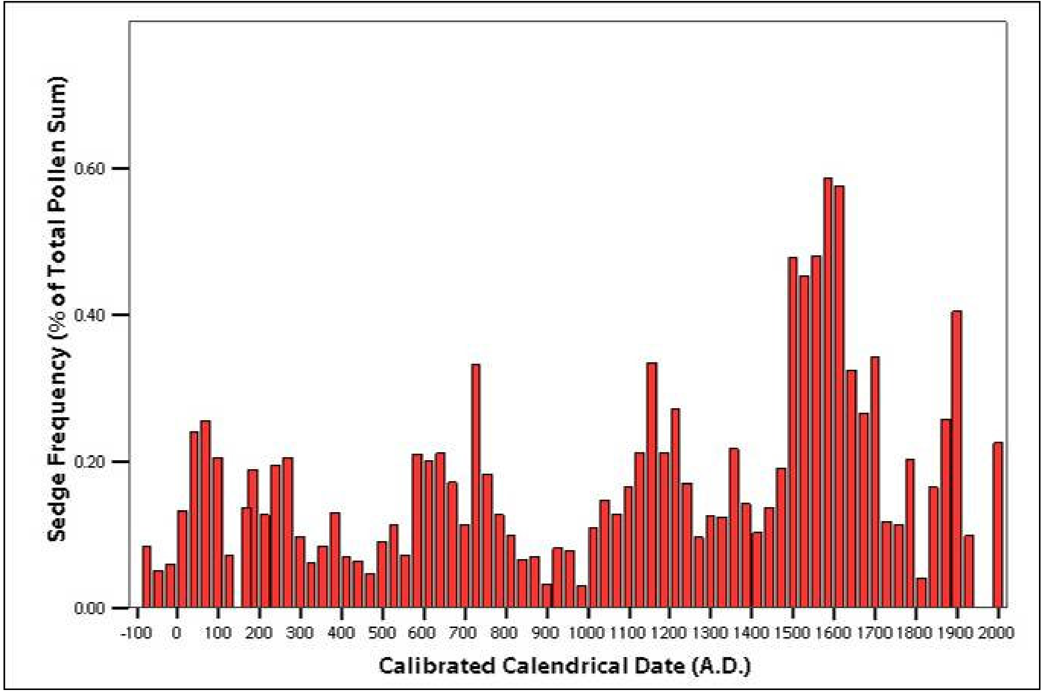


Percentages of ponderosa pine pollen in each sample plotted by the estimated calendrical date.

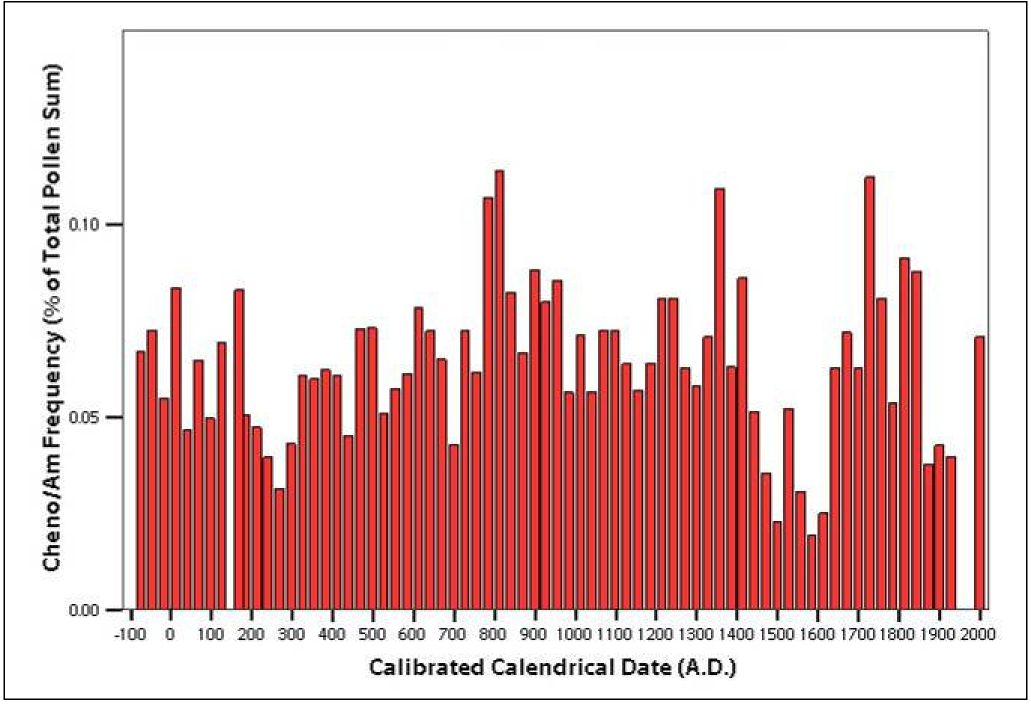


APPENDIX B: BARCHARTS OF THE POLLEN PERCENTAGES AND INFLUX RATES FOR EACH INDICATOR TAXON

Percentages of sedge pollen in each sample plotted by the estimated calendrical date.

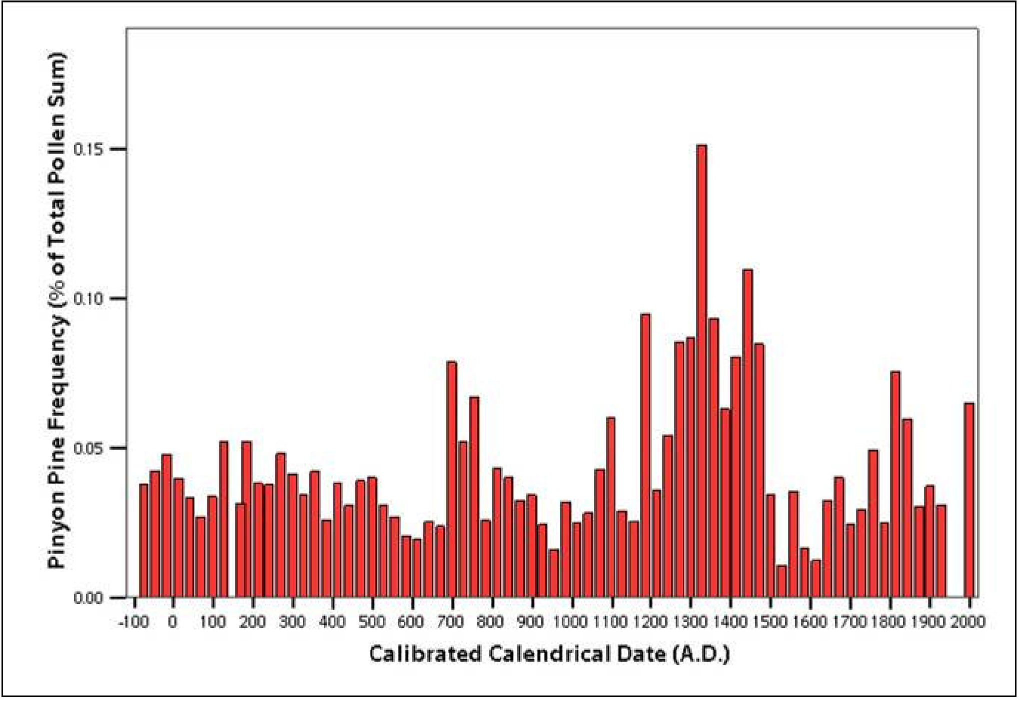


Percentages of Cheno/Am pollen in each sample plotted by the estimated calendrical date.

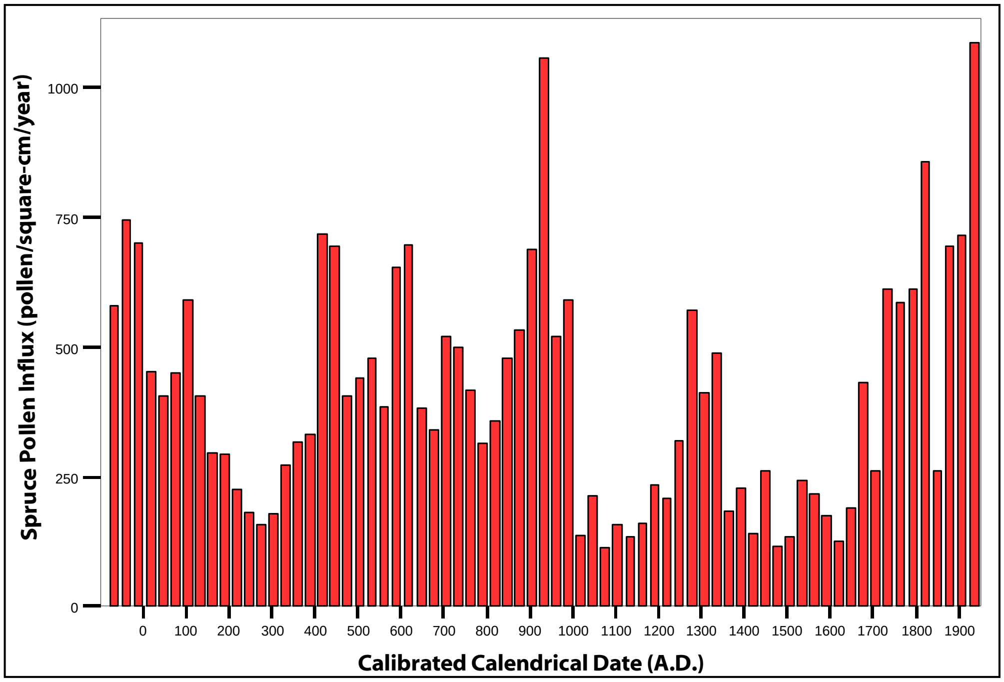


APPENDIX B: BARCHARTS OF THE POLLEN PERCENTAGES AND INFLUX RATES FOR EACH INDICATOR TAXON

Percentages of pinyon pine pollen in each sample plotted by the estimated calendrical date.

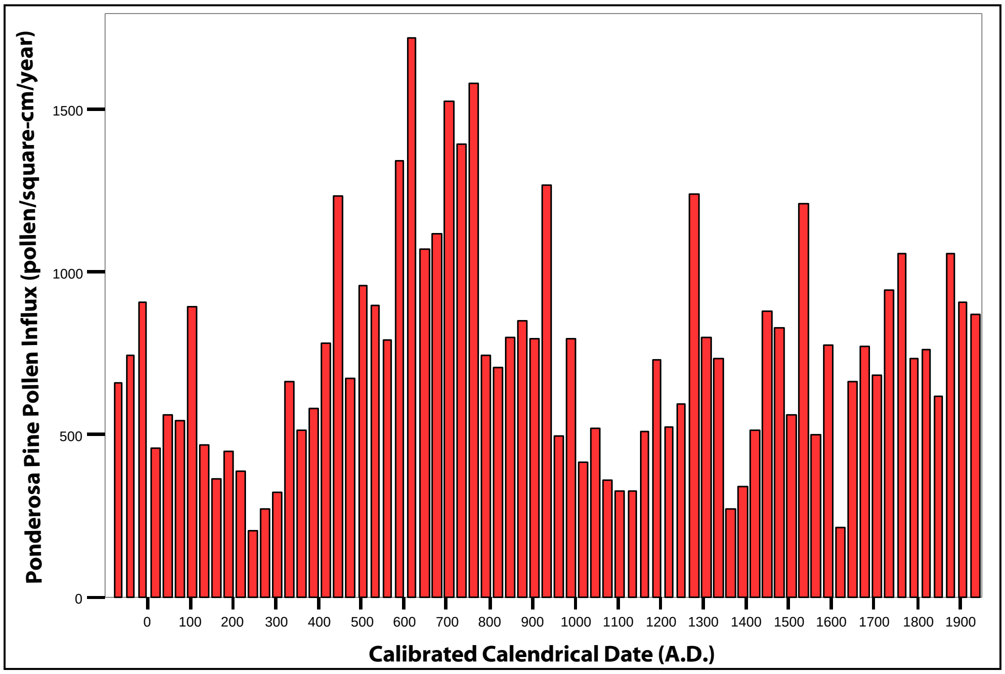


Spruce pollen influx estimates plotted by each sample's calibrated calendrical date.

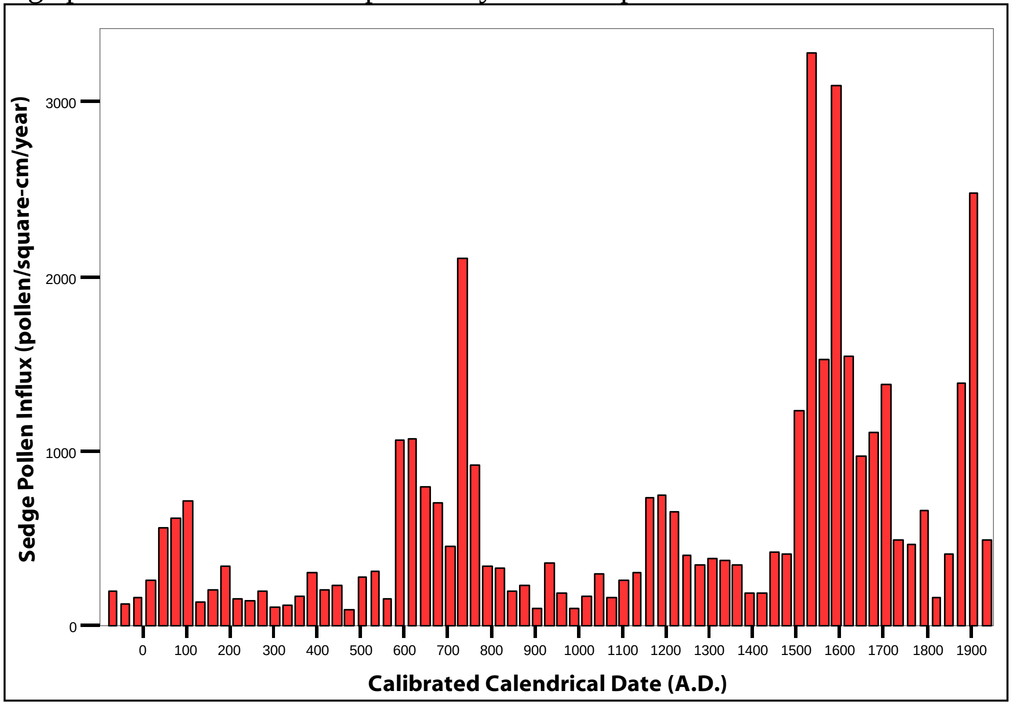


APPENDIX B: BARCHARTS OF THE POLLEN PERCENTAGES AND INFLUX RATES FOR EACH INDICATOR TAXON

Ponderosa pine pollen influx estimates plotted by each sample's calibrated calendrical date.

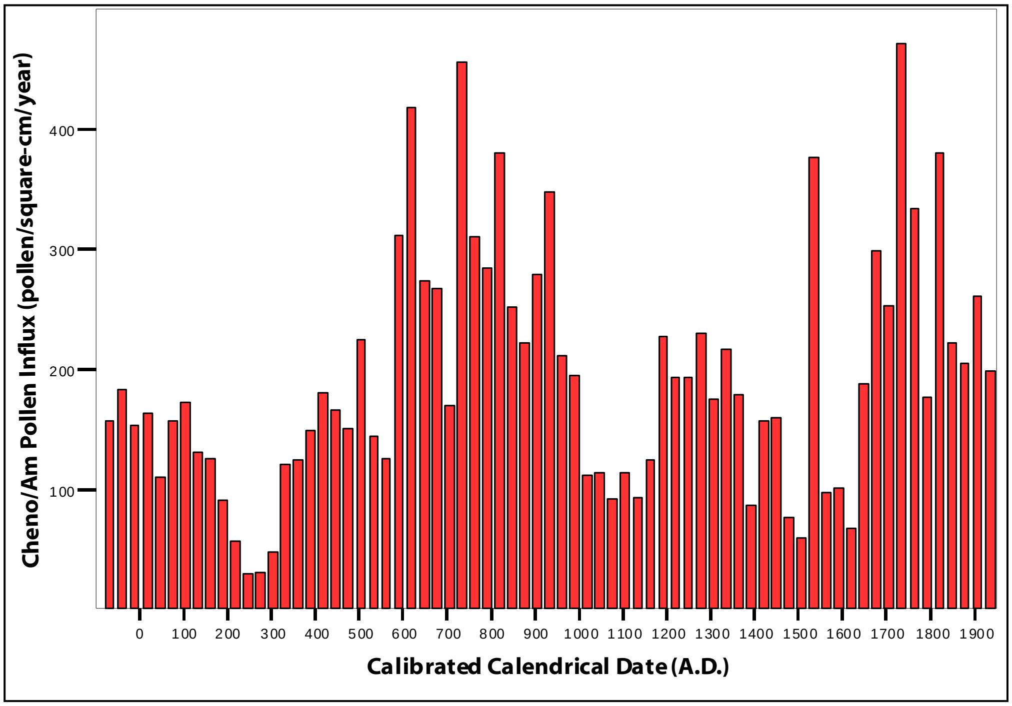


Sedge pollen influx estimates plotted by each sample's calibrated calendrical date.



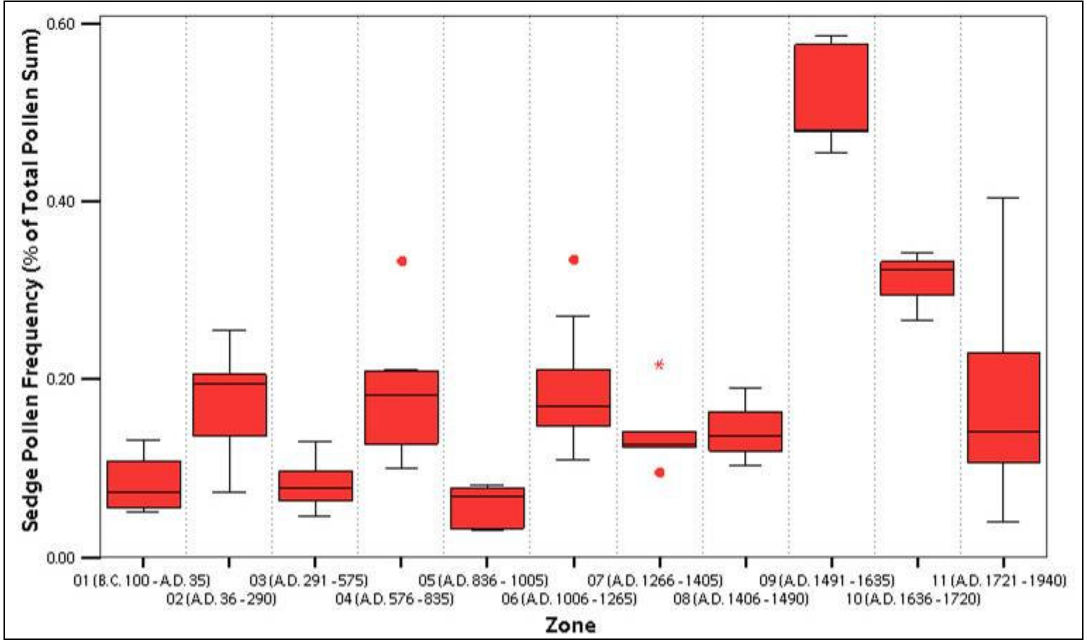
APPENDIX B: BARCHARTS OF THE POLLEN PERCENTAGES AND INFLUX RATES FOR EACH INDICATOR TAXON

Cheno/Am pollen influx estimates plotted by each sample's calibrated calendrical date.

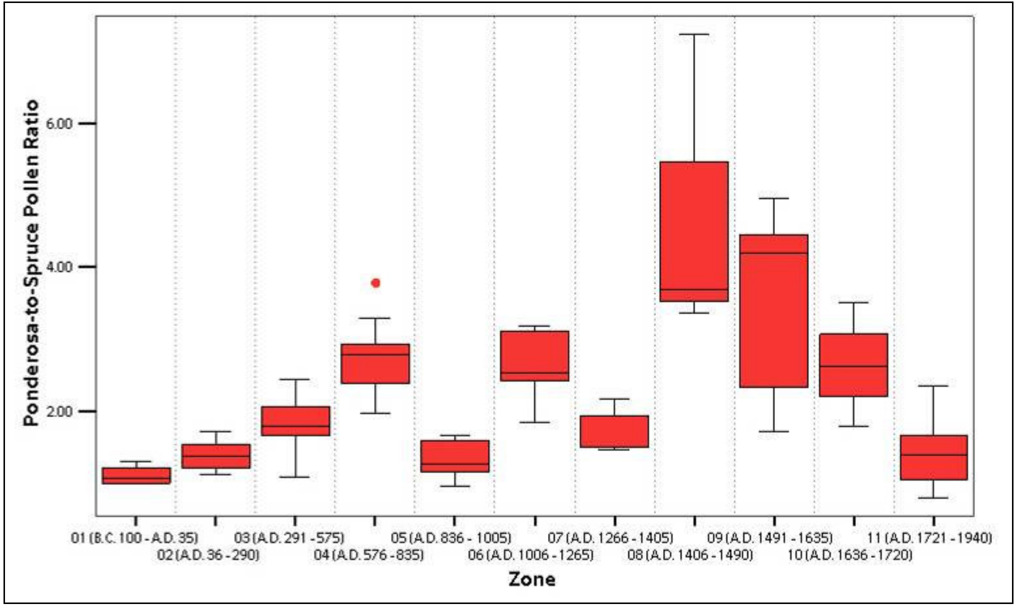


APPENDIX C: BOXPLOTS OF THE POLLEN PERCENTAGES, RATIOS AND INFLUX RATES FOR EACH INDICATOR TAXON GROUPED BY ZONE

Boxplots of spruce pollen frequencies grouped by zone.

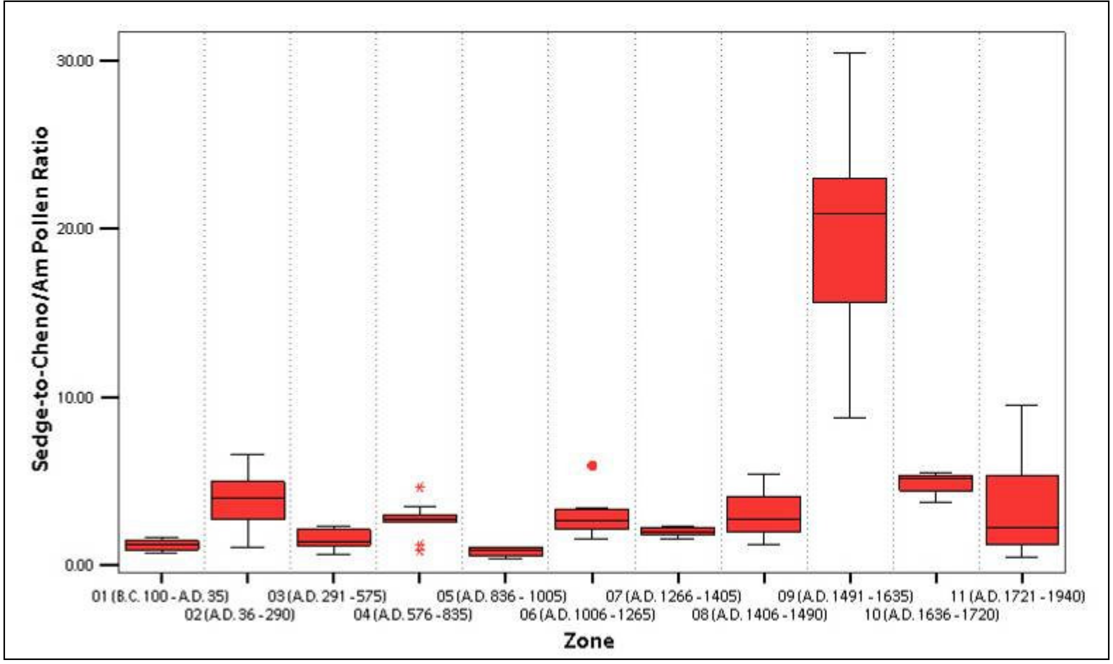


Boxplots of ponderosa pine-to-spruce pollen ratios grouped by zone.

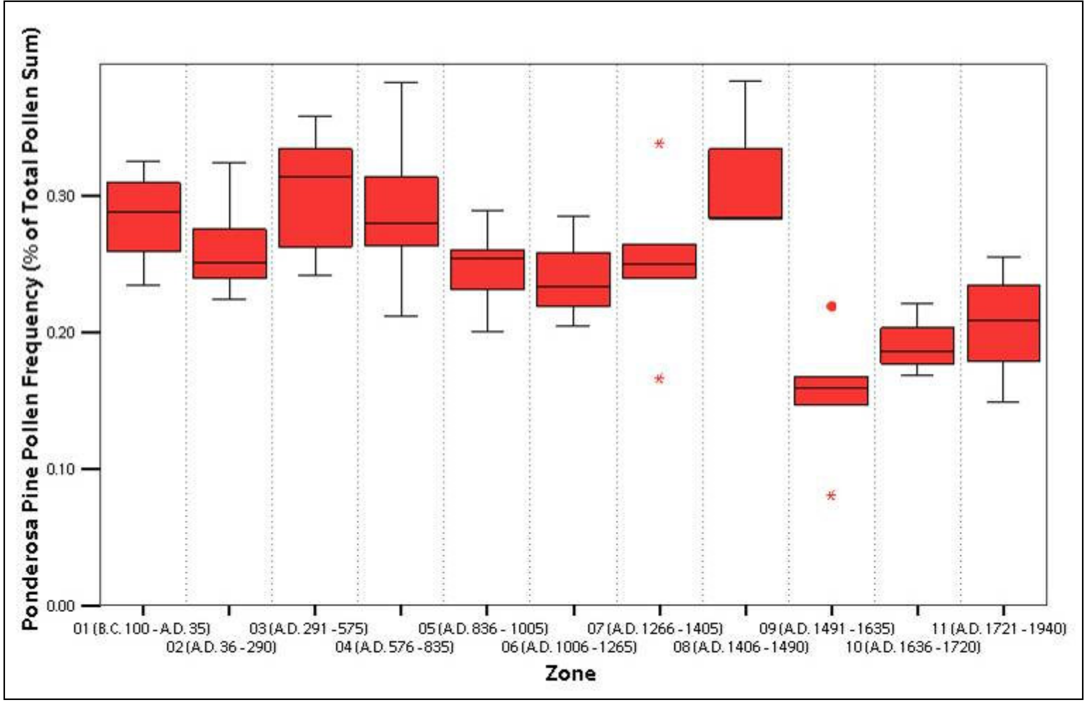


APPENDIX C: BOXPLOTS OF THE POLLEN PERCENTAGES, RATIOS AND INFLUX RATES FOR EACH INDICATOR TAXON GROUPED BY ZONE

Boxplots of sedge-to-Cheno/Am pollen ratios grouped by zone.

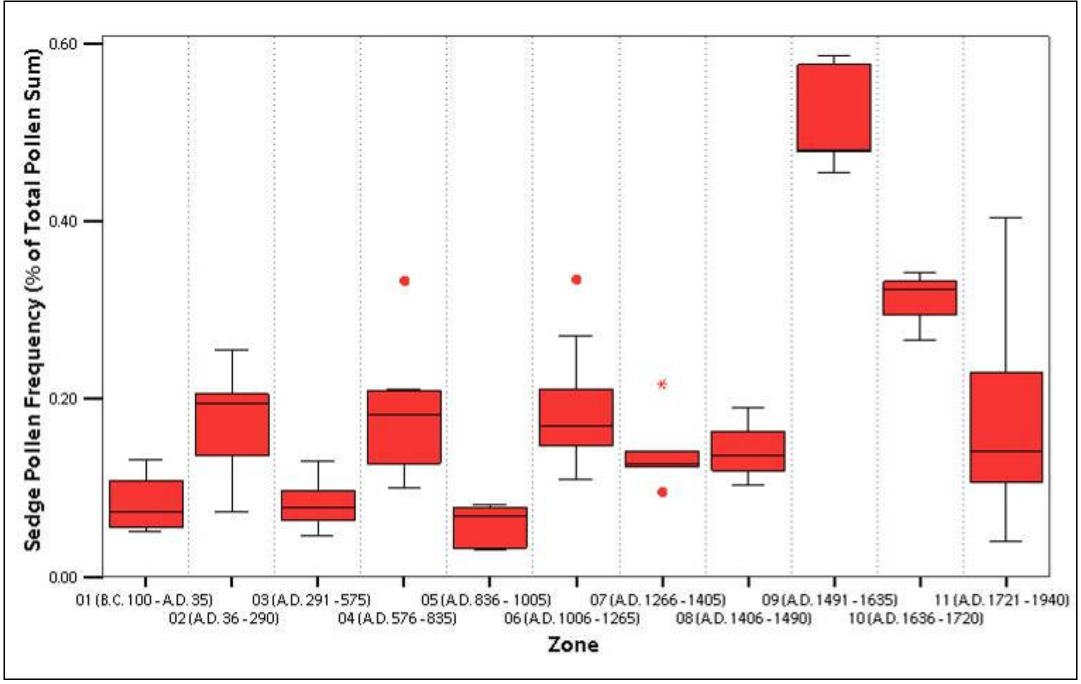


Boxplots of ponderosa pollen frequencies grouped by zone.

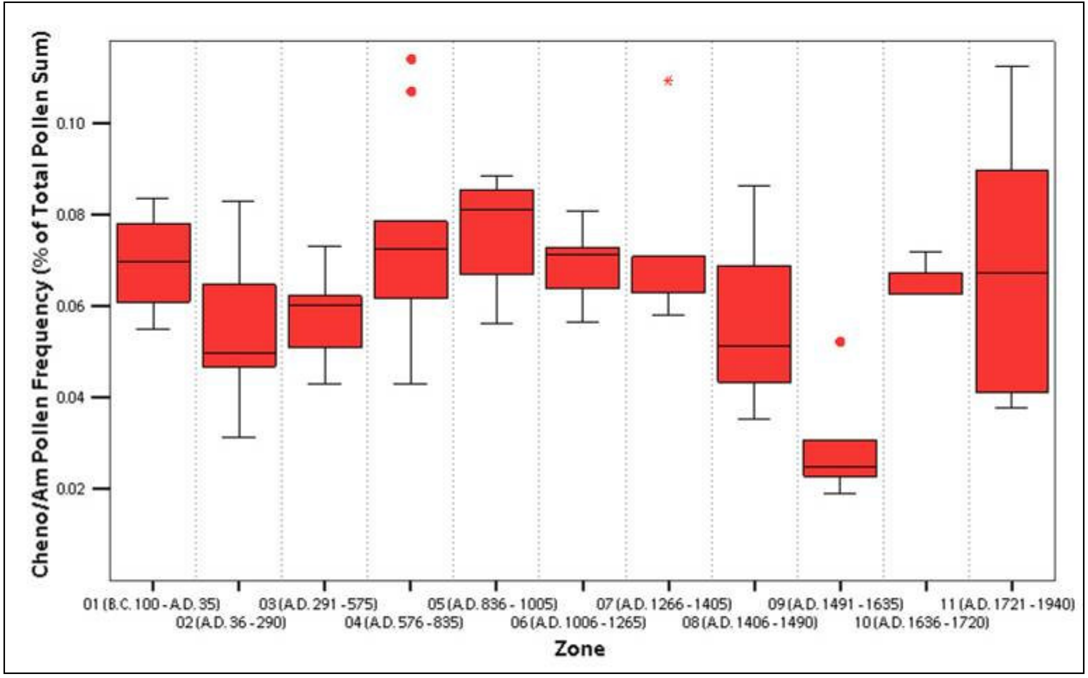


APPENDIX C: BOXPLOTS OF THE POLLEN PERCENTAGES, RATIOS AND INFLUX RATES FOR EACH INDICATOR TAXON GROUPED BY ZONE

Boxplots of sedge pollen frequencies grouped by zone.

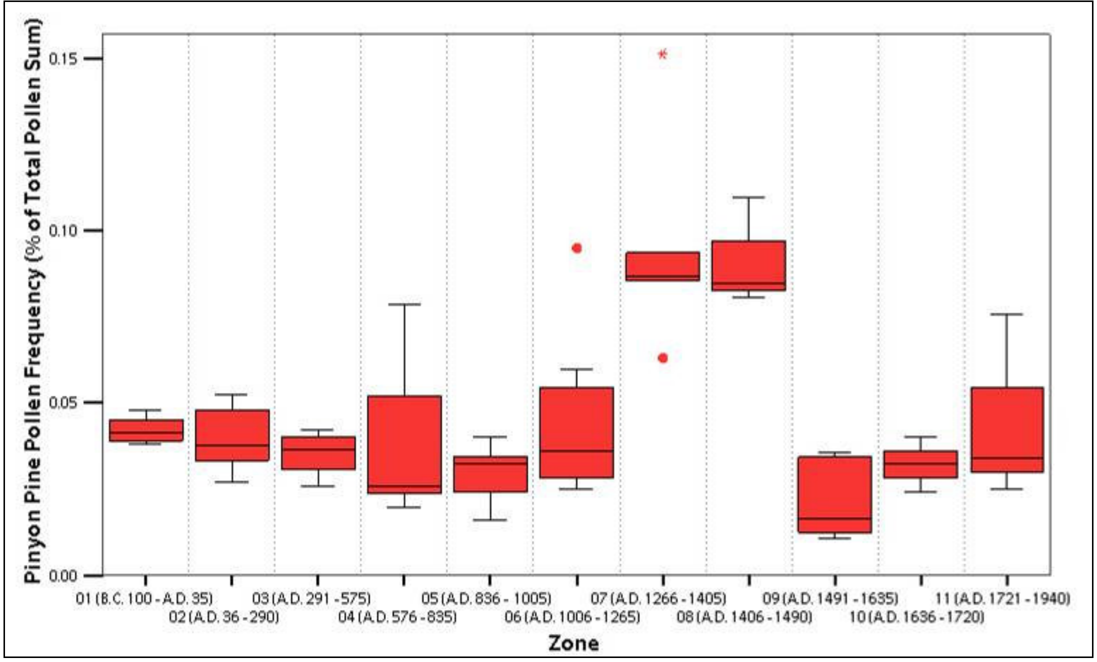


Boxplots of Cheno/Am pollen frequencies grouped by zone.

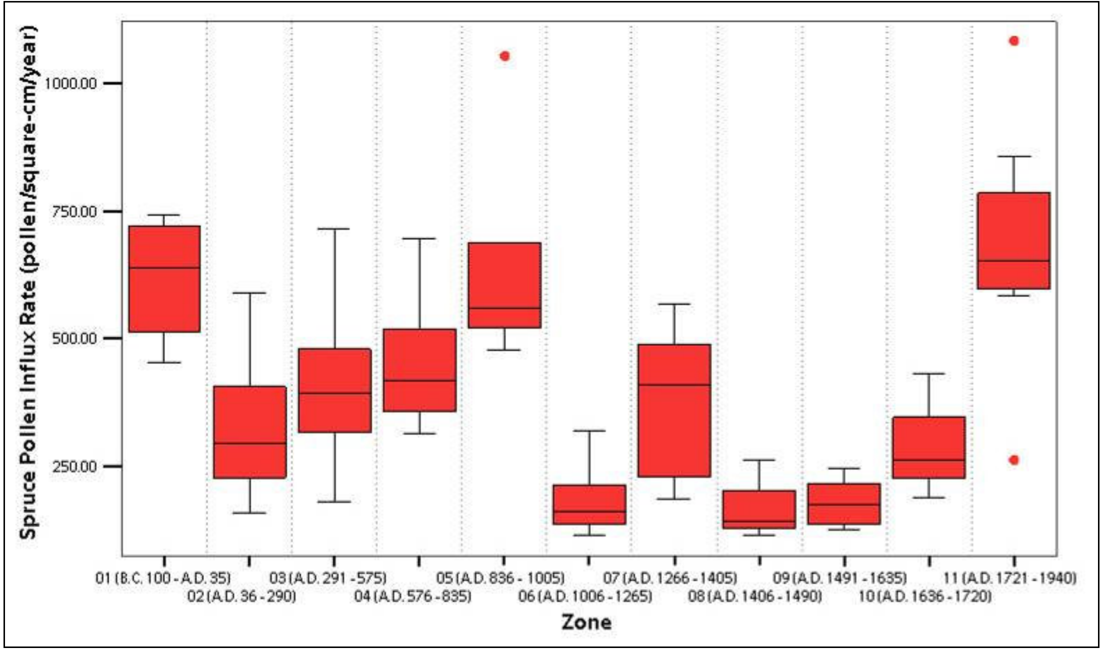


APPENDIX C: BOXPLOTS OF THE POLLEN PERCENTAGES, RATIOS AND INFLUX RATES FOR EACH INDICATOR TAXON GROUPED BY ZONE

Boxplots of pinyon pine pollen frequencies grouped by zone.

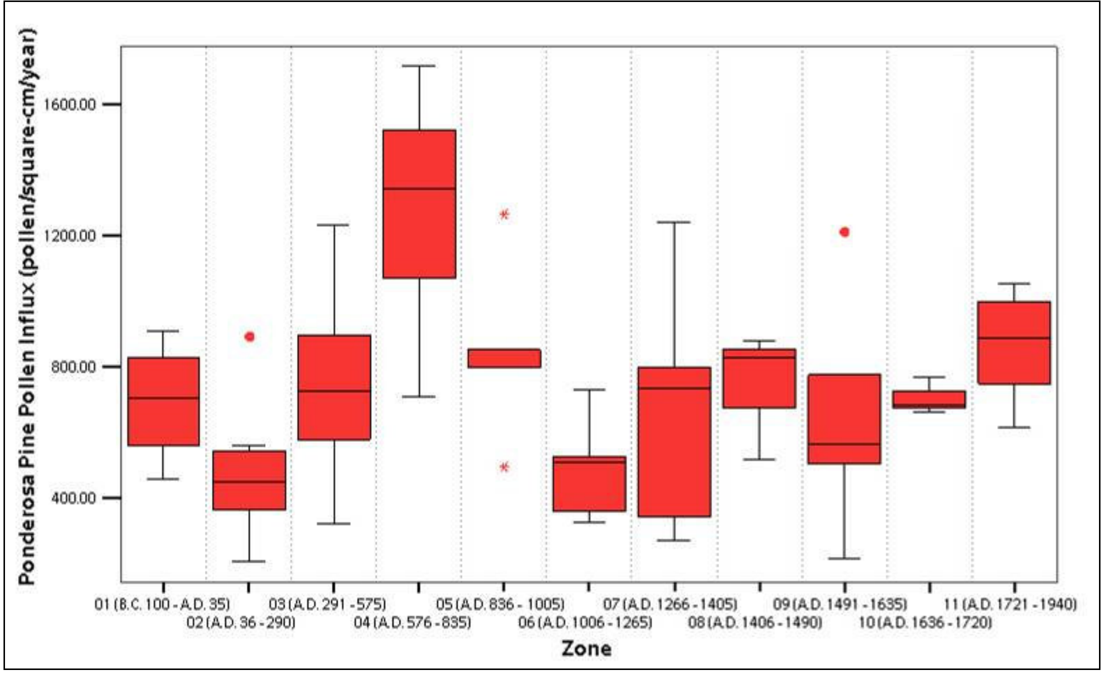


Boxplots of spruce pollen influx rates grouped by zone.

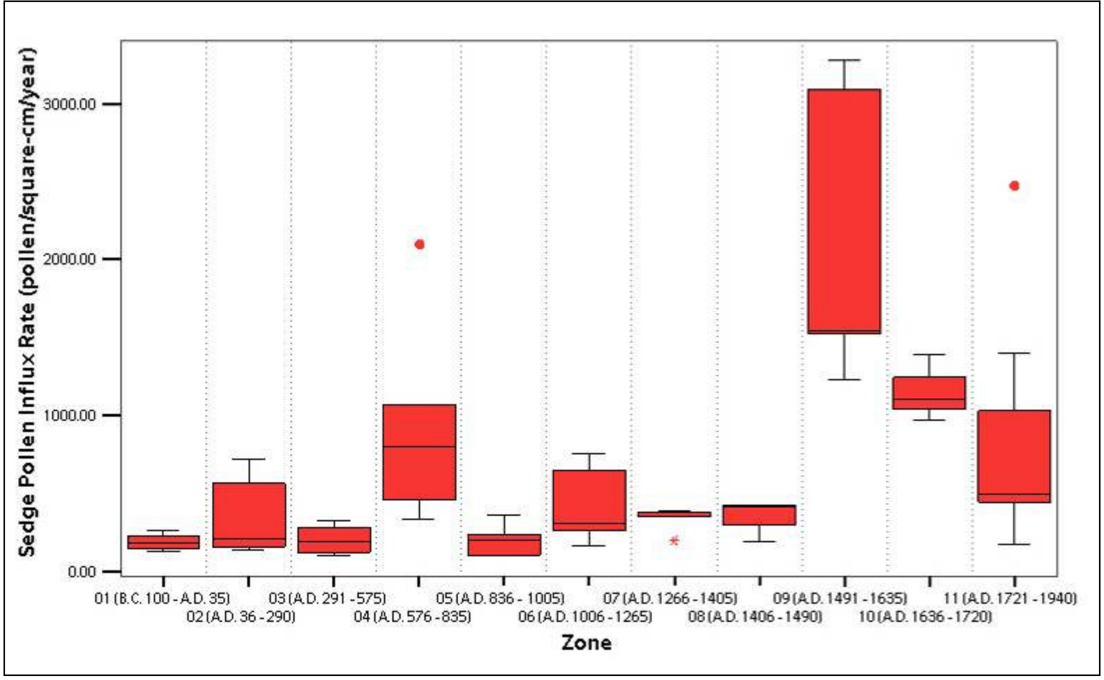


APPENDIX C: BOXPLOTS OF THE POLLEN PERCENTAGES, RATIOS AND INFLUX RATES FOR EACH INDICATOR TAXON GROUPED BY ZONE

Boxplots of ponderosa pine pollen influx rates grouped by zone.

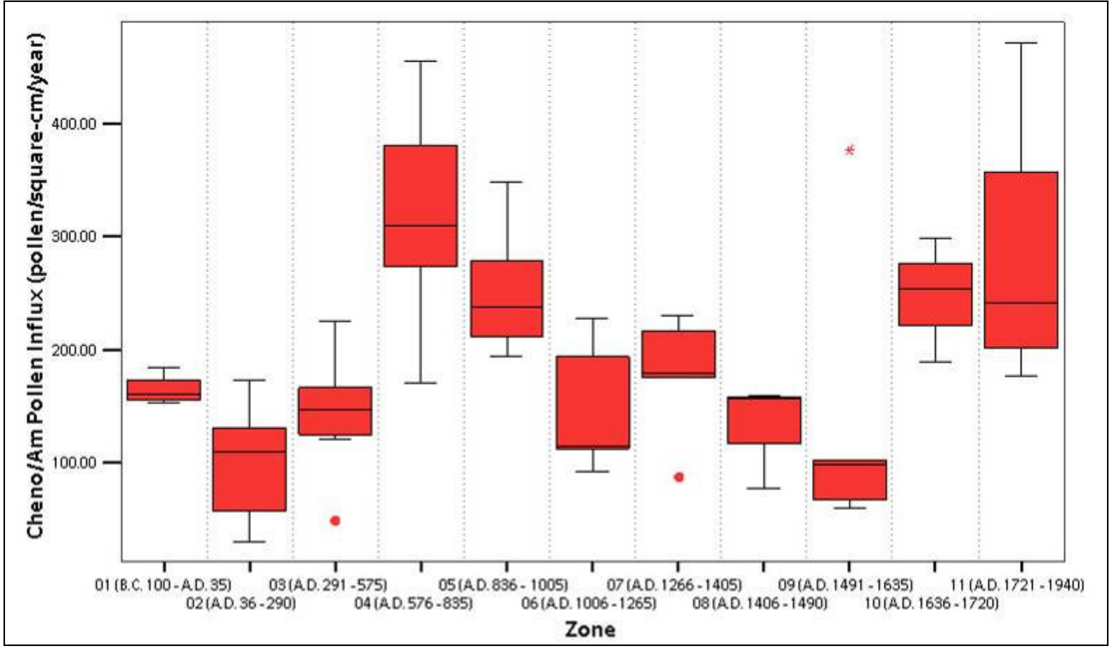


Boxplots of sedge pollen influx rates grouped by zone.



APPENDIX C: BOXPLOTS OF THE POLLEN PERCENTAGES, RATIOS AND INFLUX RATES FOR EACH INDICATOR TAXON GROUPED BY ZONE

Boxplots of Cheno/Am pollen influx rates grouped by zones.



Boxplots of pinyon pine pollen influx rates grouped by zone.