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Fire, vegetation, and Ancestral Pueblos: A sediment record from Prater Canyon in Mesa Verde National Park, Colorado, USA

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Abstract
Continuous sediment, charcoal, and pollen records were developed from a ~7-m sediment core from Prater Canyon in Mesa Verde National Park (MEVE), Colorado, USA. Sediment input into the canyon is episodic and is linked to precipitation runoff and vegetation cover. Pollen recovered from the Prater Canyon sediment core reflect the vegetation changes within the MEVE region. During the period recorded, the vegetation of the region surrounding Prater Canyon transitioned from xeric adapted species in an open environment to a more mesic, Pinus edulis-Juniperus osteosperma (pinyon-juniper) woodland over the last 1500 years. Two distinct changes in fire frequency occurred. Before 4080 cal. yr BP, fires occurred at a much more frequent rate (2.5–12 fires/200 years) than from 4060 cal. yr BP to present (0–2 fires/200 years). Most importantly, the variations occurring in the charcoal record for the past 2500 years coincide with both shifts in human occupation and climate fluctuations within the region, with burning increasing during Ancestral Puebloan occupation and moist but increasingly dry conditions, and declines in both at the end of the ‘Medieval Climate Anomaly’ (MCA). The record from Prater Canyon demonstrates the importance of the Ancestral Pueblos in landscape modification during their occupation from AD 1 to 1300. Charcoal deposition also increased during the 20th- to 21st-century transition with the highest deposition rates of the core recorded then.

Keywords
Ancestral Puebloans, climate, fire, Holocene, Mesa Verde National Park, pollen

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Introduction

Mesa Verde National Park (MEVE) is best known for some of the most spectacular prehistoric cliff dwellings and numerous pueblos and pit houses found in southwestern North America. The Park was established in 1906 primarily to preserve these numerous archaeological treasures (Public Law 34-616 Enabling Legislation for Mesa Verde National Park, 1906), which document a long history of human occupation, especially over the last c. 2500 years. For instance, Ancestral Puebloans continuously occupied the southern portions of what is now MEVE from approximately AD 1–1300 (Cordell et al., 2007; Flint-Lacey, 2003; Varien and Wilshusen, 2002). The Ancestral Puebloan population increased substantially between about AD 600 and 1300 as village structures developed and the land was cultivated for farming (Kohler et al., 2008), but both rapidly declined thereafter.

Although our knowledge of the long history of intense human occupation there is becoming clearer, our understanding of the relationship between human occupation and fire occurrence in this region is less clear. More is known concerning the most recent century than those earlier times. Subsequent to the Park’s establishment, suppression of all fires became a management goal. Throughout the Southwest, fire suppression efforts combined with several wet years in the late 20th century, followed by several dry years, created a situation ideal for the occurrence of large fires. Over the past few decades, several large fires burned within and surrounding the Park (Floyd et al., 2000, 2004, 2006). The impact of these fires has caused park managers to consider the importance of fire in this vegetation type (Floyd et al., 2004) and to speculate on the general relationship between humans, climate, and fire.

Region-wide, the impact of climate on vegetation and fire event frequency (FEF) has been the subject of numerous recent studies in the southwestern United States, including those using tree-rings (Allen et al., 2008; Gray et al., 2003; Grissino-Mayer, 1996; Salzer and Kipfmueller, 2005), stand age data (Floyd and Colyer, 2003; Floyd et al., 2000), and sediment cores (Anderson et al., 2008a, 2008b; Jiménez-Moreno et al., 2008, 2011; Petersen and Mehringer, 1976; Toney and Anderson, 2006). Although their high temporal resolution greatly aids both climatic and fire history reconstructions, tree-ring records generally represent a relatively short time scale (c. 400 years), rarely longer. Stand age data are used to reconstruct fire histories which operate under the inherent assumption that following a disturbance, most of the antecedent forest is cleared and is replaced by new growth (Everett et al., 2008). By determining the age of the stand, the timing of the last significant disturbance can be determined (Floyd et al., 2000).

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Some of the limitations of this method include that (1) fire does not burn evenly across the landscape making it difficult to pinpoint the exact timing of the fire, (2) not all trees may be established at the same time because of dispersal limitations, and (3) the resolution of this record can only provide evidence on a short time scale (about 20–1000 years). Sediment cores can be used to reconstruct changes in climate, vegetation, and FEF over longer periods, but have their own limitations. The temporal resolution of sediment cores is dependent on the rate of sediment accumulation and the preservation of charcoal and pollen. Understanding an area’s FEF is very valuable to land managers in identifying a landscape’s range of natural variability, determining desired future conditions, and modeling the future sustainability of vegetative communities under differing climatic regimes.

Within the MEVE region, most of the sediment records originate from high- and mid-elevation sites within the *Picea engelmannii–Abies lasiocarpa* forests (Anderson et al., 2008a; Toney and Anderson, 2006). Until now, continuous low to middle elevation sediment records in the MEVE region have not been generated. This lack of data has created a gap in the known history of vegetation, climate, and fire interactions within the region for the pygmy conifer woodlands to mixed conifer forest zones. In order to investigate these complex relationships, we present data from sediments obtained from a moist canyon bottom, Prater Canyon, within MEVE in southwestern Colorado that reflects the general history of fire and vegetation at a low elevation site that has been influenced by human activity for the last 2000 years.

**Setting**

MEVE is located in southwestern Colorado near the town of Cortez. The study site is located in Prater Canyon in the northeast section of MEVE (Figure 1) at 2300 m elevation, 37°17’1.2″N, 108°25’32.4″W. The general landscape consists of a southward dipping cuesta, with the highest point of the Park (Point Lookout) at 2560 m in elevation. Deep, steep-walled valleys and canyons oriented north to south separate each ridge and mesa. The drainage of the mesas is mainly toward the south, and large canyons within MEVE have cut upstream until they have reached or nearly reached the north rim of the Park. Water is the major agent of erosion that has shaped MEVE (Gillam, 2003).

Sediment enters Prater Canyon both from erosion of the north rim of the Park where the canyon originates as well as from the steep walls of sandstone that surround the canyon. No perennial stream flows in the canyon today, and it is likely that ephemeral streams that flow down the canyon during times of high precipitation or increased snowmelt, and sheet flow off the steep canyon sides, move much of the sediment especially after wildfires. Sediment input into the canyon is thus episodic and is linked to precipitation runoff events (i.e. rainfall and snowmelt; Wright et al., 2005).

MEVE has an average annual maximum and minimum temperature of 16.9°C and 2.6°C, respectively (Figure 2; Western Regional Climate Center (WRCC), 2012). In the central southern region of the park, the average annual precipitation in the area is 46 cm. while the average snowfall is 203.7 cm (climate station...
2012.

Figure 2. Average monthly climatic conditions for Mesa Verde National Park, Colorado, USA (2134 m) from 16 February 1922 to 27 February 2012.

Source: Data Compiled from Western Regional Climate Center (WRCC; 2012).

Precipitation falls almost all year round in the Park. During the early summer months (late May to June), the area is relatively dry, but in late summer (July to August), precipitation increases with the onset of the southwest monsoon. During the winter months, MEVE receives most of its precipitation in the form of snow.

The vegetation of MEVE is dominated by evergreen woodlands of *Pinus edulis* (piñon) and *Juniperus osteosperma* (Utah juniper) at lower elevations and shrubland with scattered stands of mixed conifer woodlands at higher elevations (Colyer, 2003). Primary woody plant species at lower elevations also include *Artemisia tridentata* (big sagebrush), *Purshia tridentata* (bitterbrush), *Peraphyllum ramosissimum* (Indian-apple), *Fendlera rapicola* (fendlerbrush), along with various grasses (Floyd and Colyer, 2003). At the higher elevations, the landscape is dominated by deciduous shrubs (petran chaparral), including *Quercus gambelii* (Gambel oak), *Amelanchier utahensis* (Utah serviceberry), and *Artemisia nova* (black sagebrush) mixed with trees such as *Pseudotsuga menziesii* (Douglas-fir), *P. edulis*, *J. osteosperma*, and *Juniperus scopulorum*. The canyon walls and ridges above the site of Prater Canyon Core 06-03 are populated by these species. Vegetation in the bottom of Prater Canyon consists of grasses, small shrubs, members of the Asteraceae (daisy) family, and some wetland species such as *Juncus balticus* (Baltic rush) and *Carex* (sedge). A small number of *Pinus ponderosa* (ponderosa pine) still grows nearby in Morefield Canyon immediate east of Prater Canyon.

### Methods

Three sediment cores were taken with a Livingstone corer in April 2006 on the flat canyon bottom approximately 2 km downstream from the uppermost section of the canyon, and 50 m from the canyon walls (Figure 1c). The longest, Core 06-03, at 6.97 m long (37°17′8″N, 108°25′19″W), was selected for analysis. In the lab, cores were sectioned and sediment stratigraphy was determined by visual inspection. Magnetic susceptibility was determined using a Bartington MS2E meter at 0.5-cm intervals to detect changes in sedimentation and sediment sources.

A total of 45 samples were taken every 5–20 cm throughout the length of the core. Each sample consisted of 5 cm³ of sediment and was processed using a modified Faegri et al. (1989) technique for pollen analysis, which included steps used for pollen extraction from inorganic sediments (Cwynar et al., 1979; Smith, 2003), and the addition of *Lycopodium* tracers for pollen concentration calculation. Processed samples were stained and pollen was examined at 400× magnification. Pollen identifications were made to the lowest taxonomic level possible based on published keys (Faegri et al., 1989; Kapp, 2000) and the modern pollen reference collection at the Laboratory of Paleoecology, Northern Arizona University. The Asteraceae was differentiated into four categories: Tubuliflorae-type (sunflower), *Ambrosia*-type (bur-sage), Liguliflorae-type (lettuce subfamily), and *Artemisia* (sagebrush). *Pinus* (pine) grains were differentiated into *Pinus* and *Strobus* sub genera-types based upon the presence or absence of verrucae on the leptoma. The pollen data were converted to percentages and plotted using Tilia (Grimm, 1987). Pollen zones are based on a constrained cluster analysis on the pollen record (CONISS; Grimm, 1987).

The chronology of PC 06-03 was determined using various dating techniques. Each of the 10 AMS 14C samples consisted of charcoal sieved from whole sediment samples and sent to the Keck Lab at University of California, Irvine for analysis. Radiocarbon ages were converted to calibrated calendar ages (cal. yr BP) using CALIB 4.3 (Stuiver and Reimer, 1993; Table 1). Samples for 210Pb and 137Cs consisted of whole (2–5 g) sediment samples dried overnight in an oven. Excess 210Pb and fallout 137Cs activities were measured non-destructively by gamma spectrometry using a high-resolution, low-background well-type Ge detector in order to detect a peak which would represent a date of AD 1950 (Appleby, 2001; Table 2). High-resolution sedimentary charcoal analysis for Core 06-03 followed techniques outlined by Long et al. (1998) using a volumetric sample size of 0.5 cm³ every centimeter throughout the entire length of the core. The samples were wet-sieved into two 125–250 µm and >250 µm size fractions. All charcoal particles within each sample were counted using a dissecting microscope at ~50× magnification. Peaks of charcoal abundance were evaluated using procedures delineated by Whitlock and Anderson (2003). In order to determine the FEF, additional statistical analyses were calculated using the CharAnalysis charcoal analysis program (Higuera et al., 2009).

### Results and interpretation

The chronology of the PC 06-03 core was based on 10 AMS dates obtained throughout the core (Table 1). A sample was taken near the core base (691.1–693.5 cm) to determine the overall age of the record (4818 ± 24 cal. yr BP). Three dates above the basal date occur in stratigraphic order but three samples (UCI37267,
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UCI41627, UCI37268) dating between 128.9 and 286.6 cm depth are out of stratigraphic sequence, being older than the core basal date. These were not used for age–depth reconstructions as they probably represent older re-deposited material. Three additional dates (UCI43339, UCI41636, UCI47266) from the core above 128.9 cm are in stratigraphic order. In all, 10 samples from the upper 40 cm of the core were also analyzed for excess 210Pb and fallout 137Cs (Table 2). A regression curve suggesting a deposition rate of 0.059 ± 0.009 mm/yr was constructed using all 10 samples taken from the top 40 cm of the core (Figure 3). Since the sedimentation rate was relatively slow for the 210Pb, the 137Cs curve was used for age determination. We believe the 137Cs sample taken at 21.2 cm represents the date of AD 1950. We created an age model using Clam (Blaauw, 2010; version 2.2) with linear interpolation using the seven radiocarbon dates, the 137Cs date, and the date the core was taken (Figure 4).

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Depth (cm)</th>
<th>210Pb (dpm/g)</th>
<th>226Ra (dpm/g)</th>
<th>Excess 210Pb (dpm/g)</th>
<th>137Cs (dpm/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC-01</td>
<td>1.5–4.5</td>
<td>17.96 ± 1.16</td>
<td>1.10 ± 0.15</td>
<td>16.86 ± 1.17</td>
<td>3.13 ± 0.18</td>
</tr>
<tr>
<td>PC-02</td>
<td>6.1–9.3</td>
<td>13.69 ± 1.05</td>
<td>0.93 ± 0.16</td>
<td>12.76 ± 1.06</td>
<td>1.49 ± 0.18</td>
</tr>
<tr>
<td>PC-03</td>
<td>12.1–15.2</td>
<td>6.02 ± 0.59</td>
<td>0.57 ± 0.08</td>
<td>5.45 ± 0.60</td>
<td>0.95 ± 0.08</td>
</tr>
<tr>
<td>PC-04</td>
<td>18.2–21.2</td>
<td>6.56 ± 0.58</td>
<td>0.96 ± 0.08</td>
<td>5.60 ± 0.59</td>
<td>1.78 ± 0.09</td>
</tr>
<tr>
<td>PC-05</td>
<td>21.2–24.2</td>
<td>6.73 ± 0.62</td>
<td>0.99 ± 0.09</td>
<td>5.74 ± 0.63</td>
<td>1.72 ± 0.10</td>
</tr>
<tr>
<td>PC-06</td>
<td>24.2–27.3</td>
<td>5.72 ± 0.64</td>
<td>1.21 ± 0.09</td>
<td>4.51 ± 0.65</td>
<td>1.58 ± 0.10</td>
</tr>
<tr>
<td>PC-07</td>
<td>27.3–30.3</td>
<td>5.60 ± 0.71</td>
<td>1.51 ± 0.10</td>
<td>4.45 ± 0.72</td>
<td>1.46 ± 0.12</td>
</tr>
<tr>
<td>PC-08</td>
<td>30.3–33.3</td>
<td>3.35 ± 0.61</td>
<td>1.07 ± 0.09</td>
<td>2.28 ± 0.62</td>
<td>0.96 ± 0.09</td>
</tr>
<tr>
<td>PC-09</td>
<td>33.3–36.4</td>
<td>1.81 ± 0.58</td>
<td>1.21 ± 0.08</td>
<td>0.60 ± 0.59</td>
<td>0.55 ± 0.08</td>
</tr>
<tr>
<td>PC-10</td>
<td>36.4–39.4</td>
<td>3.85 ± 0.69</td>
<td>1.16 ± 0.10</td>
<td>2.69 ± 0.70</td>
<td>0.25 ± 0.10</td>
</tr>
</tbody>
</table>

dpm: disintegrations per min.

Figure 3. 137Cs and ln (210Pbex) versus Prater Canyon core 06-03 depth. The peak in 137Cs near 20 cm corresponds to AD 1964.
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**Sediments and paleoenvironments**

Analysis of the sediment lithology revealed two major changes during the deposition of the core. The top of the core (81.2–0 cm) consists of highly organic (peaty) sediment, including roots and plant debris. The rest of the core consists primarily of sandy units of different size and composition with interbedded clay and silt. Sediments deposited between 679.0 and 287.6 cm (4819 and 4080 cal. yr BP) consist mainly of medium- to coarse-grained sand. The sediments directly above this (287.6–123.7 cm) are mostly coarse sand, massive and poorly sorted – there are no fine beds apparent in this section. These sedimentary changes correspond largely to changes in pollen and charcoal, as described below.

**Late–middle to late Holocene (c. 4800–4080 cal. yr BP; 679–287.6 cm)**

This period includes pollen zone PC-1. Pollen percentages in PC-1 include *Artemisia* (10–45%), *Ambrosia*-type (25–35%), *Atriplex*-type (13–40%), and *Juniperus* (4–12%), with relatively low percentages of Liguliflorae-type (0–2%) and *Pinus* (5–15%) present. The modern pollen assemblages at the site include *Pinus* (58%), *Atriplex*-type (16%), *Artemisia* (9%), *Ambrosia*-type (7%), *Juniperus* (4%), *Poaceae* (3%), and *Liguliflorae* (<1%; Figure 5). Comparison of the two assemblages shows that during PC-1, shrubs such as *Artemisia* and other members of the Asteraceae family were more abundant and *P. edulis* was less abundant than today (Figure 5). Higher *Juniperus* percentages suggest a rather arid *Juniperus* shrubland existed in Prater Canyon during the transition of the middle to the late Holocene and a time when *P. edulis* must have been rather rare. Pollen concentrations and magnetic susceptibility measurements (Figure 5) are extremely variable throughout this zone. The sedimentation rate in this section was very high (0.246–5.105 cm/year), while the overall pollen concentration was low (Figure 5). Charcoal concentrations during this time were fairly high and variable with two of the five largest peaks occurring near the top of this zone (Figure 6). The low pollen concentration, the presence of sand, and the high sedimentation rate indicate that this section of the core was deposited during a very active time in the canyon. The rapid sediment accumulation undoubtedly influenced the pollen concentration because the canyon floor was not left exposed for long enough periods of time for pollen to accumulate.

**Late Holocene (c. 4080–4060 cal. yr BP; 287.6–123.7 cm)**

In addition to the coarser, more poorly sorted nature of the sediments, pollen concentrations in this section are so low as to be uncountable. We believe that this section represents coarse material that was deposited on the canyon floor in a major debris flow event that occurred almost instantaneously. If the sediments were deposited at a relatively slow rate, pollen concentrations would be near values elsewhere in the core. However, if sediments were deposited rapidly, then the pollen concentration would be relatively low because of the high influx of sand from the headwaters and sidewalls of the canyon.

The charcoal stratigraphy immediately below this unit also indicates the occurrence of a rapidly deposited slug of sediment, such as that which occurs in a debris flow. The very high charcoal accumulation rates (CHARs; before 4080 cal. yr BP; Figure 5) suggest that the vegetation on canyon side slopes may have burned multiple times over a short period of time as suggested by the charcoal peaks identified (Figure 5). We hypothesize that fire burned the vegetation surrounding the canyon, destabilizing the slope and allowing for sediment and soil failure, thus moving large amounts of sediment into the canyon. This hypothesis is supported by the occurrence of three radiocarbon dates that are very much older than dates immediately above and below (Table 1). One important conclusion that can be drawn from this is that post-fire erosion and debris flows are natural phenomena that occurred within the canyon long before Euro-Americans moved into the region and began modifying the landscape.

**Late Holocene (4060 cal. yr BP to AD 2006 (~56 cal. yr BP); 123.7–0 cm)**

Accumulated sediment above the debris flow deposit (above 123.7 cm) is fundamentally different than any other section of the
Figure 5. Pollen diagram of selected taxa, magnetic susceptibility (MagSus), charcoal accumulation rate (CHAR), fire event frequency (FEF), and identified charcoal peaks for Prater Canyon core 06-03. Shading behind graphs represents a 10× exaggeration of values. Pollen diagram graphed on age scale and PC-2, the debris flow, is not included in this diagram.
core. Sediments change from primarily sand to peat at 81.3 cm (Figure 5). This core section includes both pollen zones PC-3 and PC-4 (Figure 5).

Pollen assemblages from PC-3 (123.7–100 cm) date from 4060 to 2440 cal. yr BP. This section has relatively high pollen percentages of Atriplex-type (30–38%), Tubuliflorae-type and Ambrosia-type (20–25%), Artemisia (15–20%), Pinus (10–20%), and relatively low percentages of Poaceae (8–14%), Juniperus (8–12%), and Liguliflorae-type (<1%). This section of the core had very slow rates of deposition (0.024–0.117 cm/year) and very little variability in magnetic susceptibility. This zone marks the transition from an open environment (more herbaceous and shrub species) to a more wooded (increase in Pinus pollen) environment. FEF decreased during this time causing the slopes of the canyon to be relatively stable, perhaps because of expansion of the P. edulis woodland there, with little sediment moving to the canyon bottom. The occurrence of peaty sediment in this part of the core also suggests relatively higher water tables during this period, a conclusion supported – at least currently – by patches of Baltic rush (J. balticus) growing on the surface of the meadow today.

Pollen in the uppermost zone PC-4 (100–0 cm; 2440 to ~56 cal. yr BP; 490 BCE to AD 2006) includes the highest percentages of both Pinus (15–60%) and Liguliflorae-type (0–25%), with declines in Atriplex-type (8–30%), Ambrosia-type (10–25%), Artemisia (5–25%), Poaceae (2–15%), and Juniperus (2–12%) pollen percentages. These pollen assemblages are consistent with modern pollen assemblages within the P. edulis and J. osteosperma woodland communities currently in the area (Floyd and Colyer, 2003; Murray et al., 2008). In research conducted at nearby Ridges Basin, pollen percentages of P. edulis above 20% generally predicted the occurrence of a P. edulis–J. osteosperma woodland (Murray et al., 2008). Although variable today, occurrence of Juniperus pollen together with P. edulis pollen indicates the presence of a P. edulis–J. osteosperma woodland (Murray et al., 2008). Based on this, we hypothesize that the P. edulis–J. osteosperma woodland currently within the region was not established until about 1550 cal. yr BP (when pine reached 20%). Before this time, the area surrounding the canyon was a more open woodland, with vegetation consisting of Poaceae and members of the Asteraceae, Atriplex-type, and few trees.

The primary trend throughout the last 2000 years is an increase in Pinus and Liguliflorae pollen, with a corresponding decrease in Atriplex-type and Poaceae pollen. This increase in Pinus percentage, primarily P. edulis, in the late Holocene is well documented in other records from the areas nearby (e.g. Anderson et al., 2008a, 2008b). The increase in P. edulis pollen in lake sediments from the nearby southern Rocky Mountains during the late ~4700 cal. yr BP may be attributed to an increase in winter precipitation (Anderson and Feiler, 2009; Anderson et al., 2008a, 2008b) or declining seasonality from changes in Earth’s orbital parameters (increased winter and summer insolation) and/or enhanced ENSO variability (Holmgren et al., 2007). P. edulis is believed to have expanded its range greatly because of long-distance seed dispersal in the late Holocene (Anderson and Feiler, 2009; Betancourt et al., 1991; Jackson et al., 2005). The increase in P. edulis has been seen in many different records in the Southwest, such as Neotoma sp. packrat middens in areas where there are no lakes (Betancourt and Van Devender, 1981; Betancourt et al., 1991; Jackson et al., 2005).

The vegetation surrounding Prater Canyon prior to the late 20th-century fires was a mixed conifer forest consisting of open P. menziesii and Q. gambelii, with some P. ponderosa, piñon, and juniper woodland tree elements crowning over a chapparral of deciduous shrubs. Given that assessment, the pollen record from Prater Canyon probably reflects a more regional signal than a local one because the paleorecord indicates a P. edulis–J. osteosperma woodland existed there. Not all of the pollen types from the modern vegetation were found in the Prater Canyon fossil pollen record. This may be attributed to two reasons: (1) the pollen was not preserved in the core (e.g. P. menziesii has a delicate pollen grain that is not easily preserved) or (2) the pollen was not deposited into the canyon.

Fire history

The sediments from the Prater Canyon core record charcoal from fires that occurred locally over at least the last 4819 years (Figure 5). Much of the variability in the charcoal record occurs before 4080 cal. yr BP. From 4819 to 4080 cal. yr BP, the CHAR values are higher than almost every other section of the core (Figure 5), and it is likely that this period represents one of regular and frequent fire in the drainage basin, with peaks in CHAR in this area of the core representing individual fires that occurred during this time. Also during this time, the highest FEF (2.5–12 fires/200 years) in the record occurs (Figure 5). However, we cannot exclude the possibility that the number of fires were fewer and that the number of the peaks represent re-erosion or continuous erosion of charcoal from the steep slopes of the drainage basin. This may have occurred because the margins of error for the two
changes in the remainder of the core suggest a lower FEF. For instance, from 4060 to −56 cal. yr BP (2104 BCE to AD 2006), the FEF decreased and varied between 0 and 2 fires per 200 years, suggesting a very infrequent fire regime (Figure 5).

The past 2500 years

The continual presence of charcoal between c. 4060 and −56 cal. yr BP (2104 BCE to AD 2006) confirms that fire was an important process in MEVE. Perhaps in no period is this more apparent than during the most recent 2500 years. In order to explore the co-occurrence of human occupation, landscape processes, and climatic change, we compared important late-Holocene climatic events, including the ‘Medieval Climate Anomaly’ (MCA) and ‘Little Ice Age’ (LIA) and the record of human occupation (Kohler et al., 2008) with the charcoal record (Figure 6). Ancestral Puebloans moved into the MEVE region approximately AD 1, but did not initially occupy village sites (i.e. pueblos and cliff dwellings) until AD 600 (Cordell et al., 2007; Flint-Lacey, 2003; Varien and Wilshusen, 2002). During the time of Puebloan population expansion, c. 1450–700 cal. yr BP (AD 500–1250), there is a significantly increasing trend in charcoal accumulation (Figure 6). In addition, maximum charcoal influx occurs during the latter half of the MCA, contemporaneous with the highest estimated native population in the area. Population decline in the late 13th century is accompanied by declining charcoal influx. The MCA, lasting approximately 500 years (1140–740 cal. yr BP; AD 810–1210; Dean, 1994; Petersen, 1994) witnessed fluctuating climate, but with an overall trend toward warmer and drier conditions (Dean, 1994; Grissino-Mayer, 1996; Salzer and Kipfmueller, 2005).

Archaeological evidence suggests that Ancestral Puebloans abandoned the Mesa Verde region about AD 1300 as a result of prolonged droughts, increasing population, and more extensive use of the land with consequent soil deterioration, mesa-top deforestation, and reduced harvests (Badenhorst and Driver, 2009; Flint-Lacey, 2003; Schoenwetter and Dittert, 1968). This contention has been supported most recently by Kohler and Varien (2012), who examined Ancestral Puebloan migration and settlement patterns in the MEVE area, concluding that Puebloans abandoned the area because of a combination of increasing population during climatic deterioration. An increasing population was suggested by the increase in the number of largely compacted settlements in the region. Zea mays (maize), which the Puebloans consumed as a main dietary staple, was intensively grown at lower elevations in MEVE, and region-wide. With climatic warming, the production of Z mays decreased (as documented from refuse locations at archaeological sites), accompanied by increasing reliance on wild plant foods (‘starvation foods’; Kohler et al., 2008). This may not have been enough to support the relatively large Puebloan population, with decline and emigration becoming inevitable.

We can currently only speculate on the direct relationship between burning, as recorded in sedimentary charcoal, and the presence of humans. Clearly, increases in charcoal influx preceded the major population increase (Figure 6). Even so, the co-occurrence of the fire/population proxies lends strong evidence to the importance of Native American use of fire to manipulate landscapes (Fowler, 2007). This manipulation of the fire regime by humans is clearly seen when climate became warmer and drier. Although there is no evidence of Ancestral Puebloan occupation in the immediate area near Core 06-03 core site, it is possible that the use of fire to maintain more open landscapes or improve food animal populations (mule deer, elk, bighorn, cottontails) and keeping the chaparral from becoming impenetrable to human result of human activities at lower elevation.

The LIA may also be recorded in the fire history from Core 06-03. Succeeding the MCA, the LIA lasted variously from AD 1300 to 1800 (Mann, 2002), and witnessed generally fewer fires because the climate was cooler and wetter than it was previously (Mann, 2002; Marlon et al., 2012; Petersen, 1994; Power et al., 2012). This general trend toward fewer fires continued into the 20th century at MEVE (Figure 6; see below).

Our long-term charcoal record partially explains the patterns noted by Romme et al. (2003) and Floyd et al. (2004), who determined that few fires of any consequence had occurred in this piñon–juniper forest in the last c. 600 years, probably because of discontinuous fuels. Our data suggest that immediately prior to that, however, fire was more common in the region as expanded human population probably increased human–landscape interactions. Perhaps not coincidentally, many of the ancient piñon–juniper forests were established in the decades and centuries since the Ancestral Puebloans departed and FEF decreased. We suggest that a complex series of factors involving human settlement, climate, natural and anthropogenic ignition sources, and fuels have combined to determine the importance of fire in the Mesa Verde piñon–juniper woodlands.

Although apparently the LIA was time-transgressive worldwide (Mann, 2002), the climatic record of reduced fire is complicated in the MEVE region by the arrival of Euro-American settlers in the 19th century. These settlers may have perpetuated minimal fire occurrence, as charcoal concentrations, CHAR, and FEF remain low during this time (Figures 5 and 6). This is in contrast to the Marlon et al. (2012) regional study, which suggested increased burning during the 19th century. In the Southwest, however, numerous studies (e.g. Covington et al., 1997; Miller and Wigand, 1994) have documented that intensive grazing altered fire regimes by removal of fine fuels. Prior to 1906, when MEVE became a national park, grazing occurred on these government-owned lands, and administrative Park records show that grazing continued in the north end of the Park until the 1930s (Romme et al., 2003). This policy may have inadvertently contributed to the trend of minimal fire activity in the Park until late in the 20th century, a period of time that Marlon et al. (2012) have termed the ‘fire deficit’ period. After the 1930s, grazing was prohibited in the Park which may have led to the buildup of fine fuels in some areas. However, many of the piñon–juniper woodlands remained with a dense canopy. In more open stands, small fires and beetle kills have led to an increase in shrubs as canopies opened. This may have increased the potential for large fires in recent times, providing abundant finer fuels for ensuing fires.

Once MEVE became established in 1906, fire suppression was instituted as a management policy (National Park Service (NPS), 2006). It is likely that fire suppression in the 20th and 21st centuries had little to no impact on the structure of old growth piñon–juniper woodlands, as suggested by Floyd et al. (2000, 2004). This is probably because of the considerably long fire turnover time in those woodlands (c. 400 or more years), as suggested by Floyd et al. (2000, 2004) and confirmed by our research. However, the amount of charcoal produced by the Bircher Fire of 2000, as shown in our sediment record (Figure 6), is unparalleled by any other time period in the entire record.

Conclusion

The Prater Canyon sediment core has produced a long record of climate, vegetation, fire history, and human influence within MEVE. Comparison of the modern pollen with modern vegetation suggests that the Prater Canyon pollen integrates the record
haps a sagebrush scrub in the valley bottom. Pollen data indicate that the present *P. edulis–J. osteosperma* woodland in the region may not have existed at its current extent in the past (Figure 5). During this time, fires occurred relatively frequently (2.5–12 times every 200 years). It is likely that vegetation on side slopes of the canyon was affected, destabilizing soils and causing one or more mass movements of sediment, ending up at the core site.

Transitioning from the middle to late Holocene, 4060–2440 cal. yr BP (2104 BCE to AD 2006), the vegetation began the change-over from sagebrush scrub to a woodland. Few fires occurred during this time as shown by an increase in FRI to nearly 900 years, which is conducive to a *P. edulis–J. osteosperma* woodland environment to become established within the region (Floyd et al., 2004, Figure 5).

For the last 2500 years, the vegetation of the region continued to transition into denser *P. edulis–J. osteosperma* woodlands, similar to what is seen in the region today, especially at lower elevations. Approximately 1550 cal. yr BP (500 AD), *P. edulis* expanded, which suggests a transition to somewhat wetter conditions. Over the course of the last 1500 years, pollen evidence documents changes showing an evolution from dry-adapted communities in an open environment to a less xeric *P. edulis–J. osteosperma* woodland and montane petran chaparral–mixed conifer community at the Prater Canyon study site. This is reflected also in sediment changes in the core. The actual timing of the development of chaparral–mixed conifer community at the Prater Canyon site is unknown because of poor pollen preservation.

One of the most important outcomes of this research is the documentation of the co-occurrence of increasing fire and Ancestral Puebloan population during the MCA (Figure 6). During the time of Ancestral Puebloan occupation (establishment of villages) and farming in the area (1450–650 cal. yr BP; AD 600–1300), the charcoal concentration increased as the human population increased (Figure 6). The highest charcoal peak within the last 4000 years occurs at 740 cal. yr BP (AD 1210), or slightly before the peak in human population (700 cal. yr BP; AD 1250). The timing of these events is so close that it may be safe to assume that these two events are contemporaneous.

Other ancient Native American populations within the present Western United States were presumed to have used fire to modify their local environment (e.g. Anderson and Carpenter, 1991; Anderson and Stillick, 2013; Anderson et al., 2013; Walsh et al., 2010), but this is the first documented evidence for the Ancestral Pueblos of the Southwest. The warmer and possibly drier climatic conditions during the MCA provided an ideal situation for fire, with increasing human population causing increasing ignition possibilities. Right before the end of the MCA, both the charcoal concentration and human occupation in the area decreased rapidly. The end of the MCA correlates with the movement of Native Americans out of the area (probably because of climate deterioration, poor maize production, and a depleted natural resource base).

Overall, charcoal deposition continued to decline until 50 cal. yr BP (AD 1900) when it reached the lowest concentration in approximately 2000 years. This decrease in charcoal correlates with the timing of the LIA when the climate was much cooler, wetter and the area was more sparsely inhabited. The most recent changes in charcoal deposition (over the last 100 years) have occurred since the Park was established. It is clear that the charcoal deposition between 4060 and ~56 cal. yr BP (2104 BCE to AD 2006) only substantially increases when human populations are larger. This is compelling evidence that humans have had a strong influence on the local fire regime over the past 2000 years.

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### References


