Pollen Analysis and Paleoenvironmental Reconstruction of Wetlands in the Monte Vista National Wildlife Refuge, San Luis Valley, Colorado

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ABSTRACT

The San Luis Valley (SLV) in south-central Colorado has a high water table and contains many wetlands. This research focused on using pollen to reconstruct the paleoenvironments of two wetlands on the Monte Vista National Wildlife Refuge (MVNWR) in the SLV. Paleo-wetland and modern wetland samples were analyzed for radiocarbon age and paleoenvironmental conditions. Loss on Ignition results show significant changes in organic matter in samples aging 11,390 ± 30 ^{14}C to present, suggesting climate changes from warm-dry to cold-wet during the Younger Dryas, then warm-dry in the early Holocene, and finally a modern strengthening of a warm-dry climate. *Picea*, *Abies*, and *Sarcobatus* results reflect these patterns, as do changes in species composition from *Abies* to *Pinus*, which suggests treeline ascension, typical of a warming climate. These data suggest that warmer conditions in the SLV result in drier conditions, which have implications for future freshwater availability and the agricultural and recreational economy in the SLV.

Keywords: pollen, peat, wetlands, climate, paleoenvironments

INTRODUCTION

Wetlands in the San Luis Valley

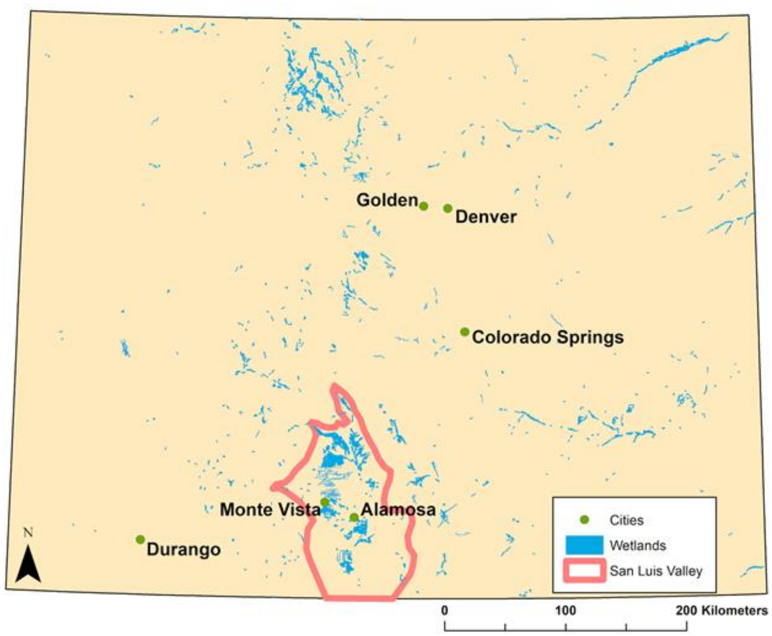

Figure 1. Locations of wetlands in Colorado. Notice how most of the wetlands are located within the SLV.

Colorado's two largest National Wildlife Refuges, Alamosa and Monte Vista[1], protect wetlands in the San Luis Valley (SLV) of south-central Colorado. These wetlands are dependent on recharge of the shallow water table by the surrounding mountains and have historically experienced heavy extraction for agriculture and waterways. Today, groundwater in the SLV is used to irrigate local agricultural fields and increase the flow of the Rio Grande.[1] To understand how water use in the SLV has changed over time, this research uses pollen analysis to reconstruct the paleoenvironments of the Scott Miller Mammoth Site (SMMS) within the Monte Vista National Wildlife Refuge (MVNWR). The purpose of the analysis is to understand how climate and water resources have changed in the area, as well as determine current trends in water use and how they might be affecting the hydrology of the wetlands. This research may be used to provide the MVNWR with more information for acquiring water rights.

Importance of Wetlands

Wetlands can be found throughout the United States in many forms and variations, supporting an immense diversity of species of flora and fauna. Some species are specially adapted to those ecosystems and many other species use the wetlands as stops during migration.[2] In general, wetlands are considered hydrological ecosystems, with most of the species living in them being dependent on the water within the wetland.[2] Wetlands are prime ecosystems for carbon sequestration and other ecosystem services because of their organically rich sediment profiles.[3] In Colorado, 90 percent of the state's fish and wildlife depend on wetlands and other riparian habitats.[1] Both ecologically and economically important to the state, wetlands make up 1.5 percent of the surface area of Colorado, totaling about one million acres.[1] Wetland benefits in Colorado include: local fish and wildlife habitat, productive grazing land, stopover and breeding grounds for migratory birds, flood impact mitigation, improved water quality, a strong outdoor tourist industry built around the wildlife and water of the wetlands, and extractive economic ventures.[1]

Conservation and Management

The United States Fish and Wildlife Service (USFWS) is the leading agency responsible for conserving, preserving, and managing the MVNWR. The MVNWR was established under the Migratory Bird Conservation Act (1929), which protects the habitats of migratory bird species and designates the wetlands to be managed as sanctuaries.[4] It is the mission of the SLV Refuge System to benefit present and future generations by conserving and managing a national system of lands and water, and restoring the habitats of fish, wildlife, and plant resources.[4]

Although the refuge overlays a confined aquifer, the water provided by this aquifer goes mostly to the wells drilled for irrigating the surrounding agriculture in the valley.[4] After the 1970s when groundwater levels declined, water management became the primary focus as the wetland habitat increasingly depended on surface water. The wetlands were once naturally supplied by the Rio Grande, then ceased as the river's hydrology was altered by intensive use, extensive irrigation networks, and diversions.[4] Spring Creek originally created the wetlands in the MVNWR but was dramatically affected as natural flows ceased due to over pumping the groundwater.[5] A few wetlands in the MVNWR were artificially created, and most wetlands and vegetation are supported by irrigation canals and wells and intensively managed to provide viable habitat.[4] Controlling and manipulating water remains the first focus of management, in addition to a greater understanding of the role and influence of groundwater on wetland habitat.

Previous Work

This research serves as an extension to the work previously done at the Scott Miller Mammoth Site (SMMS) within the MVNWR (figure 3). An abundance of mammoth and other extinct Pleistocene megafauna remains have generated a major interest in the SMMS by paleontologists, archeologists, geologists, ecologists, biologists, geographers, and environmental scientists. A paper by Beeton[6] (the leading research advisor for this research) provides precursory data that was used in combination with primary data samples taken for this study from the SMMS. Radiocarbon samples taken in 2014 by Beeton[6] of an organic silt layer and woody peat layer yielded dates of 8,740 ± 30 ^{14}C years before present (yr BP) and 11,390 ± 30

^{14}C yr BP, respectively. These layers are included in the samples taken for this 2018 study. The peat layers sampled for this study are described and interpreted by Beeton[6] and generate an understanding of an oscillating water table: at some points in time drying out the land and forming evaporate layers, while at others sousing the strata forming organic rich layers.

METHODS

Geographic Setting and Site Selection

The MVNWR is a 14,834-acre wetland located in the SLV between two mountain ranges: the Sangre de Cristos to the east, and the San Juan Mountains to the west. The eastern San Juan Mountains are early Cenozoic extrusive volcanic and volcaniclastic rocks.[7,8] The Sangre de Cristos are an uplifted and tilted Precambrian block.[9] The San Juan Mountain peaks range in elevation from 13,000 feet to 14,000 feet, and the Sangre de Cristos reach an elevation of over 14,000 feet.[10,11] Eroded sediments from the two surrounding mountain ranges settle onto the valley floor. Rain usually occurs during the months of July and August.[12]

Figure 2. Map of the SLV floor in south-central Colorado. The Sangre de Cristos are to the east and the San Juan Mountains are to the west. The polygon within the SLV is the Monte Vista National Wildlife Refuge.

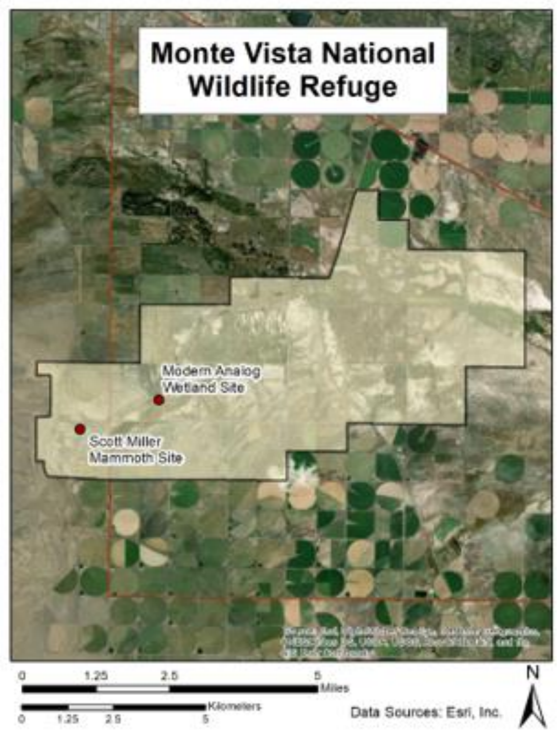

Figure 3. Map of the MVNWR, the SMMS, and the wetland where a modern analog wetland sample was collected.

Due to the lack of precipitation, which is approximately 20 cm per year, groundwater aquifers are vital to the health of the wetland ecosystems. The SLV has two aquifers: an unconfined shallow aquifer, and a deep, confined aquifer. The aquifers consist of loose clay, silt, sand, and gravel. These aquifers are separated by clay and San Juan volcanic lava beds.[4] Groundwater is present throughout the SLV floor. The water has been adjudicated for wildlife and irrigation at the Monte Vista and Alamosa NWR. The groundwater plays a major role in the survival of the wetland ecosystem.[4] A high-mountain depositional basin, the SLV spans 80 miles north-south and 50 miles east-west, and is a part of the Rio Grande Rift, a north trending continental rift zone that extends from central Colorado south to Chihuahua, Mexico.

The paleo-wetland located within the SMMS was chosen as the site of study for this research due to the previous analysis, which consisted of radiocarbon dating of the peats, by Beeton.[6] The modern wetland was chosen for study due to its proximity to the paleo-wetland.

Peat Analysis, Pollen Sampling, and Loss on Ignition

In this study three key climatic indicators were used for the reconstruction of paleoenvironments: peat analysis, pollen sampling, and loss on ignition. Peat is partially decayed vegetation and organic matter[13] and is generally composed of a minimum of 65 percent organic matter (dry weight basis) and less than 20–35 percent inorganic material.[14] Peat is primarily composed of wetland vegetation such as bog plants, mosses, sedges, and shrubs. Due to the slow accumulation, continuous growth, and receptivity of peat, it can hold thousands of years of data within its deposits. Peat samples provide records of past vegetation, and hence, climate through the pollen grains stored within them. With these data, scientists can reconstruct paleoenvironments and use that knowledge to better understand past land use.[15]

Palynology is the analysis of fossil pollen and is used to reconstruct changes in vegetation and climate.[16] Pollen can be extracted from peat samples, and each species of plant produces distinct pollen grains which can guide inference of vegetation that was growing nearby when the peat was deposited. Pollen grains sink to the bottom of water sources and stay well preserved in the sediment. Through vegetation identification, a picture of past climates can be determined. Loss on ignition (LOI) is the process of intensely heating a substance containing organic material for a specified amount of time in a high-temperature furnace to burn off any moisture to attain its dry weight and then weighing it again to determine the amount of organic matter that was burned off.

Primary Data Collection

Methods used in this research include peat collection, loss on ignition, pollen extraction, and pollen analysis. Eight peat samples were taken at two distinct research sites at the MVNWR. The first six samples were collected at the paleo-wetland within the SMMS. Peat samples were collected with a flat hand trowel at depth intervals of every 10 cm. Each layer was precisely cut to prevent cross contamination from modern pollen. After samples were taken, they were put directly into WHIRL-PAK sampling bags, which were closed immediately to prevent contamination from modern airborne pollen. The hand trowel was cleaned with water after each sample to further prevent the cross contamination of samples. The last two peat samples taken at the modern wetland site consisted of the top two cm of sediment accumulated on the wetland pond bottom. The peat samples were extracted by hand, wearing sterile gloves, and placed into WHIRL-PAK sampling bags that were immediately closed. The peat samples were submitted to the PaleoResearch Institute in Golden, Colorado for standard archaeobotanical pollen analysis. The process took six weeks and results were received in November 2018.

One peat sample from each depth and location was also collected for LOI testing to determine organic matter content. The samples were placed in crucibles and first weighed at their wet weight. The wet samples were then placed in a drying oven (100°C) for 24 hours to remove moisture content. Once removed from the drying oven, the samples were weighed immediately to determine the moisture content of the peat and to prevent the absorption of atmospheric moisture. Finally, the samples were placed in a muffle furnace (450°C) for 2 hours and 20 minutes to burn off organic matter. Once the samples were removed from the furnace, they were weighed again. The organic matter was calculated as the difference in weight from the oven-dry and the muffle furnace-dry samples.

RESULTS

Pollen analysis and LOI results are described below and shown in tables 1 and 2, respectively. Pollen analysis results were received on November 7, 2018 along with a detailed report of the findings and a pollen diagram by Cummings[17] (figure 4). LOI testing was completed during October 2018.

Table 1. Results in percent organic matter from LOI testing for each peat sample. Results show a distinct increase and decrease in organic matter.

Sample	Organic Matter (%)
SM4-3-18 (Woody Peat) (~11,390 ± 30 ^{14}C)	**27.6**
SM4-2-18 (Woody Peat) (~11,390 ± 30 ^{14}C)	**51.2**
SM4-1-18 (Organic Silt Peat) (8,740 ± 30 ^{14}C)	**20**
MAP-1-18 (Modern Wetland) (Present)	**6.25**

Pollen Sample SM4-3-18

Sample SM4-3-18 was collected at a depth of 30–32 cm below the surface and has an age of ~11,390 ± 30 ^{14}C yr BP.[6] This sample had significant quantities of locally growing *Cyperaceae* and *Poaceae* pollen, and moderate quantities of *Abies* and *Pinus* pollen.[17] Small quantities of *Amaranthaceae*, *Asteraceae*, *Caryophyllaceae*, *Rosaceae*, *Artemisia*, *Dalea*, *Eriogonum*, *Juniperus*, *Polemonium*, *Pseudotsuga*, *Quercus*, *Salix* and *Typha angustifolia*-type pollen was also found.[17] *Pinaceae and Quercus* pollen sources grew regionally, while the other pollen sources grew locally.[17] This sample had minor amounts of microscopic charcoal. The total pollen concentration was calculated as ~64,850 pollen grains/cm^3 of sediment.[17]

Pollen Sample SM4-2-18

Sample SM4-2-18 was collected at a depth of 20-22 cm below the surface. This is in the same layer dated at ~11,390 ± 30 ^{14}C yr BP but is higher stratigraphically, and thus, younger than Sample SM4-3-18.[6] This sample showed an increase in *Abies, Pinus, Salix,* and *Artemisia*, and a decrease in *Cyperaceae* pollen. However, low-spine *Asteraceae and Typha angustifolia*-type quantities remained the same.[17] There were low quantities of *Amaranthaceae*, *Asteraceae, Rosaceae, Eriogonum, Juniperus,* and *Picea*, with *Juniperus* and *Picea* growing regionally and the rest of the pollen sources growing locally.[17] These was an increased amount of microscopic charcoal compared to SM4-3-18. The total pollen concentration was calculated as ~76,000 pollen grains/cm^3 of sediment.[17]

Pollen Sample SM4-1-18

Sample SM4-1-18 was collected at a depth of 10–12 cm below the surface. This sample was dated as ~8,740 ± 30 ^{14}C yr BP.[6] *Pinus* pollen was abundantly present in this sample, but *Juniperus, Picea*, and *Pseudotsuga* pollen were no longer visible.[17] *Salix* pollen levels continue to be relatively high in concentration.[17] The following plant pollen all remain relatively similar to the previous samples: *Amaranthaceae*, *Artemisia*, low-spine *Asteraceae*, high-spine *Asteraceae, Cyperaceae*, and *Poaceae*.[17] There were small quantities of *Fabaceae, Rhamnaceae, Liguliflorae, Abies, Ceanothus, Euphorbia* and *Typha latifolia* pollen. Microscopic charcoal levels further increased compared to the older samples.[17] Total pollen concentration was calculated at ~64,000 pollen grains/cm^3 of sediment.[17]

Pollen Sample MAP-1-18

Sample MAP-1-18 was collected from the top two cm of the modern wetland sediments. This sample had significant quantities of *Artemisia* and *Pinus* pollen.[17] There were also notable, but smaller quantities, of *Poaceae* and *Sarcobatus* pollen.[17] *Asteraceae, Brassicaceae, Cyperaceae, Rosaceae, Liguliflorae, Abies, Alnus, Artemisia, Eriogonum, Euphorbia, Pseudotsuga, Salix, Sphaeralcea*, and *Typha latifolia* pollen are all represented in the pollen sample, but in small quantities.[17] Microscopic charcoal quantities were found. The total pollen concentration was calculated at ~58,900 pollen grains/cm^3 of sediment.

Table 2. Summary of species composition results from pollen analysis of each peat sample.

Samples	Pollen Analysis
SM4-3-18 (30-32 cm bs) Woody Peat ~11,390 ± 30 ^{14}C yr BP *Paleo-wetland*	Abundant: *Cyperaceae* and *Poaceae* Moderate: *Abies* and *Pinus* Few: Microscopic charcoal, *Amaranthaceae, Asteraceae*, Caryophyllaceae, Rosaceae, *Artemisia, Dalea, Eriogonum, Juniperus, Polemonium, Pseudotsuga, Quercus, Salix* and *Typha angustifolia*
SM4-2-18 (20-22 cm bs) Woody Peat ~11,390 ± 30 ^{14}C yr BP *Paleo-wetland*	Abundant: *Abies* and *Pinus* Moderate: Microscopic charcoal, *Cyperaceae, Poaceae, Artemisia* and *Salix* Few: *Amaranthaceae, Asteraceae, Rosaceae, Eriogonum, Juniperus, Picea* and *Typha angustifolia*
SM4-1-18 (10-12 cm bs) Organic Silty Peat ~8,740 ± 30 ^{14}C yr BP *Paleo-wetland*	Abundant: Microscopic charcoal and *Pinus* Moderate: *Cyperaceae, Poaceae, Artemisia* and *Salix* Few: *Amaranthaceae, Asteraceae, Fabaceae, Rhamnaceae, Liguliflorae, Abies, Ceanothus, Euphorbia* and *Typha latifolia*
MAP-1-18 (Top 2 cm) Modern Peat *Modern Wetland*	Abundant: Microscopic charcoal, *Pinus* and *Artemisia* Moderate: *Poaceae* and *Sarcobatus* Few: *Asteraceae, Brassicaceae, Cyperaceae, Rosaceae, Liguliflorae, Abies, Alnus, Artemisia, Eriogonum, Euphorbia, Pseudotsuga, Salix, Sphaeralcea*, and *Typha latifolia*

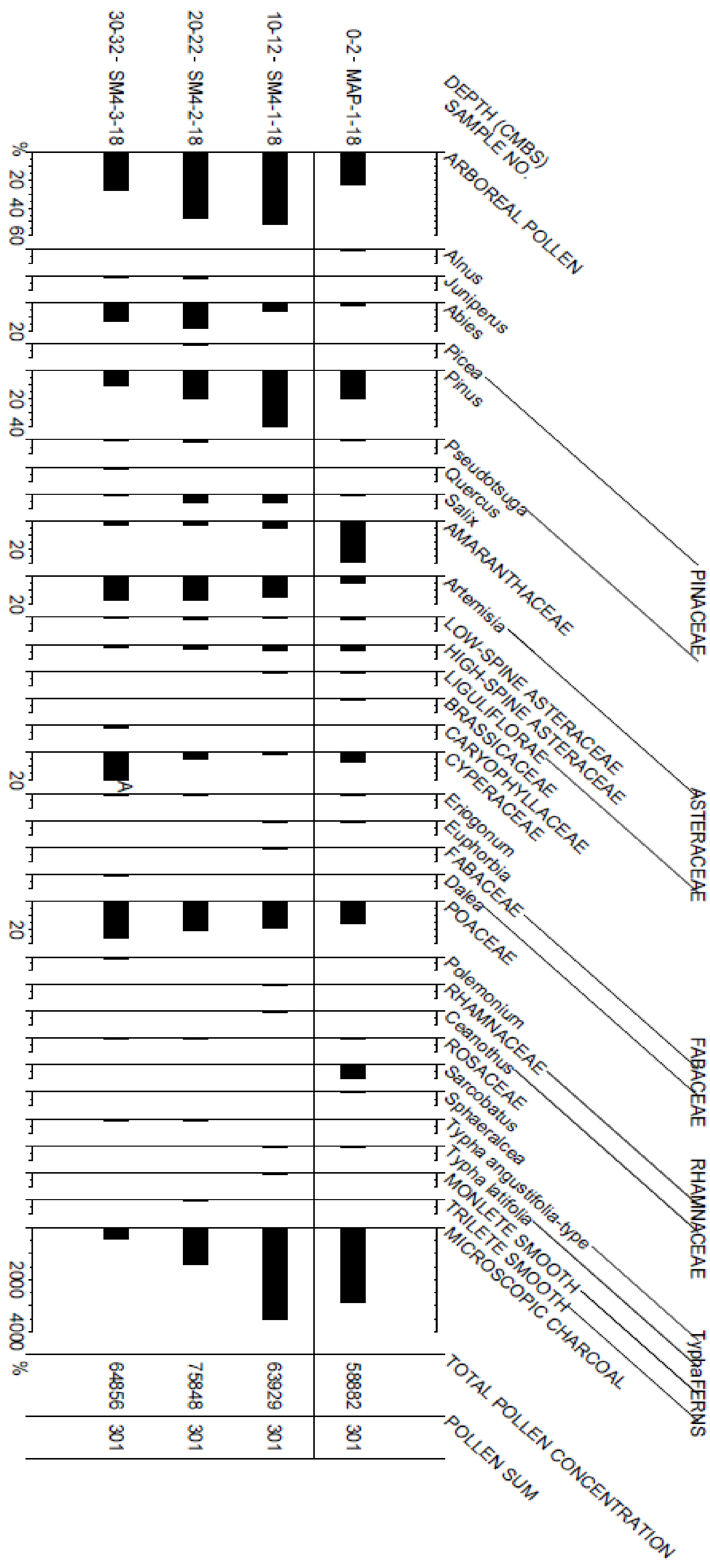

Figure 4. Pollen diagram showing pollen and charcoal concentrations for each sample. Modified from Cummings[17] (2018)

DISCUSSION AND CONCLUSIONS

LOI results show a clear fluctuation in organic matter, which, along with the relative accumulation rates of the peat samples, coincide with the timing of the YD. The rate of peat accumulation between samples SM4-3-18 and SM4-2-18, which were both dated at ~11,390 ± 30 ^{14}C yr BP, was greater than the rate of peat accumulation between samples SM4-2-18 (~11,390 ± 30 ^{14}C yr BP) and SM4-1-18 (~8,740 ± 30 ^{14}C yr BP), despite there being thousands of extra years during which peat could have accumulated. This suggests that the climate was relatively colder and wetter during the time between samples SM4-3-18 and SM4-2-18, and relatively warmer and dryer during the time between samples SM4-2-18 and SM4-1-18. LOI results for the modern analog pollen sample (MAP-1-18) suggest a further intensifying of a warmer and drier climate, which is congruent with results from modern research.

Sample SM4-3-18 showed large quantities of *Cyperaceae* and *Poaceae*, indicating that local vegetation was dominated by sedges and grasses, with a presence of *Typha* (cattails), suggesting a marsh-like environment.[17] Moderate quantities of *Abies* and *Pinus* pollen, and small quantities of *Juniperus, Pseudotsuga,* and *Quercus* pollen indicate that conifer species mixed with oaks probably grew at a higher elevation, and small quantities of *Salix* indicates that few willow species grew locally in the wetland.[17] Very little microscopic charcoal was recovered from this sample, which may indicate less wildfires in a wetter and colder climate. The growth of *Abies, Pinus, Salix,* and *Artemisia* pollen in SM4-2-18 suggests an expansion of these species, and the decline of *Cyperaceae* pollen suggests the movement of open water into the area.[17] The pollen concentrations of other species indicative of wetlands, such as low-spine *Asteraceae* and *Typha*, remained static. Evidence of an increase in microscopic charcoal compared to sample SM4-3-18 suggests an increase in wildfires or cultural fire use in the area.[17]

The maintained abundance of *Amaranthaceae, Artemisia,* low-spine *Asteraceae*, high-spine *Asteraceae, Cyperaceae,* and *Poaceae* pollen in sample SM4-1-18 represent stability in the wetland and nearby vegetation.[17] *Pinus* pollen had become abundant, while *Abies* pollen had decreased, suggesting an ascension in treeline.[18,19,20,21,22] *Juniperus, Picea*, and *Pseudotsuga* pollen are no longer visible, indicating an absence or strong decline during this time.[17] A continued increase in levels of microscopic charcoal was observed, suggesting further increase in wildfires or cultural activity.[17] *Pinus* pollen continued to rise as *Abies* pollen continued to decline in sample MAP-1-18, suggesting a further ascension of treeline and further warming. Sample MAP-1-18 also presented the first appearance of *Sarcobatus* pollen, which may allude to an increase in salinity in the surrounding soils due to the evaporation of water and wetlands resulting from a warming climate.[17] *Artemisia* pollen concentrations grew, which may also suggest a warming and drying climate. Large amounts of microscopic charcoal were also evident in this sample, but less so than sample SM4-1-18, which would correlate to the decrease in wildfire and cultural fire use since the beginning of the MVNWR and a nationalized fire suppression regime.

Our LOI and pollen results are congruent, as well as the comparison of our results with those of Head Lake,[20] Cumbres Bog,[21] and Black Mountain Lake.[22] Overall, these results show an early fluctuation in climate, transitioning into a cool and wet period ~11,390 ± 30 ^{14}C yr BP, then a general trend of warming and drying through ~8,740 ± 30 ^{14}C yr BP with enhanced warming and drying in the present. Other patterns expressed by our data, such as the ascension of treeline, increase in microscopic charcoal, and the increased amount of salinity in the area also support modern warming and drying. Current research suggests that drier conditions will prevail as the climate warms, which could harm the agricultural economy, availability of freshwater, and winter sports in the SLV.[18] This research may be used to further examine the effects of climate on wetland ecosystems. Further, it suggests that the paleo-wetlands, which are dry today, reflect a lowering of the water table in a modern warming and drying climate; this may be used to assist the MVNWR to achieve additional water rights to sustain wetland habitats.

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