FIRE AND VEGETATION HISTORY OF THE LAST 2000 YEARS IN JACKSON HOLE, GRAND TETON NATIONAL PARK, WYOMING

by

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APPROVAL

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Karen Marie Jacobs

17 January, 2007

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ABSTRACT

Fire is an important natural disturbance in the western U.S., and information on how fire occurrence has varied in the past is critical to understanding modern ecosystem processes and their link to climate change. Long-term fire and vegetation histories are obtained from charcoal and pollen records preserved in lake sediments. Most charcoal-based fire-history studies have been conducted in middle- and high-elevation forest ecosystems, where glacial and other natural lakes are abundant. We have almost no information on the long-term fire history of low-elevation forest and steppe. The last 2000 years is of particular interest because it encompasses both human-induced and natural environmental change. Pollen and high-resolution macroscopic charcoal records obtained from three lakes in Jackson Hole were studied to reconstruct the vegetation and fire history over the last 2000 years in low-elevation ecosystems. The influence of centennial-scale climate change on fire regimes was evident in the charcoal records. During the relatively dry Medieval Climate Anomaly (ca. AD 800-1300), charcoal accumulation rates decreased at a site located near the forest/steppe ecotone, which suggests that forests may have been fuel-limited and experienced fewer fires than at present. During the Little Ice Age (ca. AD 1500-1900), charcoal accumulation rates decreased at a site in lodgepole pine forest and increased at a site in sagebrush steppe, suggesting forest fuels were too wet to burn, but on the steppe combustible fine fuels increased. Euro-American settlement is also evident as a decrease in pine pollen percentages after ca. AD 1900 due to forest clearance.

INTRODUCTION

Fire is an important form of natural disturbance in nearly all terrestrial ecosystems in the western United States, and it serves as a critical link between climate change and ecosystem response (Agee, 1993; Swetnam and Betancourt, 1998). The nature of these linkages depends on the time scale of interest. On short time scales, climate/weather and vegetation characteristics affect the fire conditions of particular years (and decades), as well as the dynamics of post-fire ecological succession. On centennial and millennial time scales, large-scale changes in climate alter regional fire regimes and vegetation composition. The linkages are especially complex in the western United States, where fire regimes vary across environmental gradients and include frequent surface fires as well as infrequent stand-replacement events (Whitlock et al., 2003; Whitlock and Bartlein, 2004).

Fire-history information is obtained from two complementary data sets: tree-ring records and lake-sediment charcoal records. Tree-ring records are spatially precise but temporally limited by the age of living trees and subfossil wood (Arno and Sneck, 1977; Johnson and Gutsell, 1994; Baker and Ehle, 2001). Charcoal records, obtained from the sediments of natural lakes and wetlands, span a much longer time and are associated with pollen records that provide information on the vegetation history of an area (Whitlock et al., 2003). Most charcoal-based fire-history studies have been conducted in middle- and high-elevation forest ecosystems, where glacial and other natural lakes are abundant. Although our understanding of past fire regimes in these relatively mesic ecosystems is improving, we have almost no information on the long-term fire history of low-elevation forest and steppe, despite the fact that these ecosystems are especially sensitive to drought and land-use activities (Swetnam, 2002; McKenzie et al., 2004).

The last 2000 years of environmental history is of particular interest in climate change research because it encompasses both human-induced and natural environmental change (Jones and Mann, 2004). In Grand Teton National Park (GTNP), displacement of Native Americans and their burning activities, as well as the impacts of Euro-American trappers, miners and homesteaders likely resulted in changes in vegetation and fire regime during this time span (Daugherty, 1999). Land management practices, including fire suppression in the 20th century, have also shaped the composition and structure of forests and possibly steppe communities. Climate variations, such as the relatively dry Medieval Climate Anomaly (ca. AD 800 – 1300; Hughes and Diaz, 1994) and the Little Ice Age (ca. AD 1500 – 1900; Bradley, 1999; Cook et al., 2004), may have altered fire regimes and vegetation in GTNP, which in turn would have influenced human activities and impacts. Thus, land use, land management, climate and fire have probably created the modern low-elevation ecosystems in Grand Teton National Park, but the interactions among these variables are poorly understood.

To fill the gap in our understanding of low-elevation ecosystems, research was undertaken to develop a fire and vegetation history of the last 2000 years at three sites in the dry forest and steppe communities of GTNP. Jackson Hole at the foot of the Teton Range is exceptional in the western U.S. in having a number of natural lakes in low-elevation settings suitable for paleoecologic research. Lakes are repositories for pollen and charcoal that can be used to reconstruct the vegetation and fire histories of the surrounding area (Birks and Birks, 1980; Whitlock and Larsen, 2001). Pollen records provide information on past vegetation, and charcoal records are used to develop a local fire history. Changes in lake sediment character help assess variations in sediment input and lake conditions that might be related to shifts in lake production and watershed inputs. A chronology upon which to build the environmental history comes from radiometric dating of terrestrial organic matter in the sediments.

This investigation of Jackson Hole's history is part of a larger research effort to understand the Holocene vegetation, climate, and fire history of Greater Yellowstone Ecosystem (e.g. Whitlock, 1993; Whitlock and Bartlein, 1993; Whitlock et al., 1995; Millspaugh et al., 2004; Whitlock et al., in review). My objective was to answer the following questions about the history of Jackson Hole: What was the fire and vegetation history of the last 2000 years within Jackson Hole? What was the vegetation response to climate variations occurring in the last 2000 years (e.g. Little Ice Age, Medieval Climate Anomaly)? Were there significant similarities in the charcoal records of the past 550 years to suggest concurrent fire events? What conditions of climate, environment and vegetation gave rise to frequent and possibly widespread fire in Jackson Hole in the past? How might the ecosystem have been altered by Native American burning and Euro-American activities, including forest clearance, grazing, and introduction of non-native species? How have current management practices (including fire suppression) in the last century altered fire regimes of lower forest and steppe communities in Jackson Hole?

Three sites for this study were selected along a north-south transect of Jackson Hole (Figure 1). The sites are separated by the Snake River as it flows out of Jackson

Lake and south through the valley. Swan Lake (lat. 43.89^{o}N, long. 110.63^{o}W, elevation 2072 m; Figure 1) is surrounded by lodgepole pine (*Pinus contorta*) forest. Pothole Lake (lat. 43.78^{o}N, long. 110.62^{o}W, elevation 2033 m) is located primarily in sagebrush (*Artemisia tridentata*) steppe in the middle of the Jackson Hole. Hedrick Pond (lat. 43.73^{o}N, long. 110.59^{o}W, elevation 2048 m) lies at the ecotone between lodgepole pine (*Pinus contorta*) and Douglas-fir (*Pseudotsuga menziesii*) forest in the Gros Ventre Range to the south and east and sagebrush steppe in Jackson Hole to the west and north. Pollen and charcoal data from each site permitted a reconstruction of local changes in the low-elevation vegetation and fire regimes and the ecological responses to known centennial-scale variations in climate and human impacts. These records also permitted a comparison of fire histories along a north-south transect of Jackson Hole and a documentation of times of widespread fire.

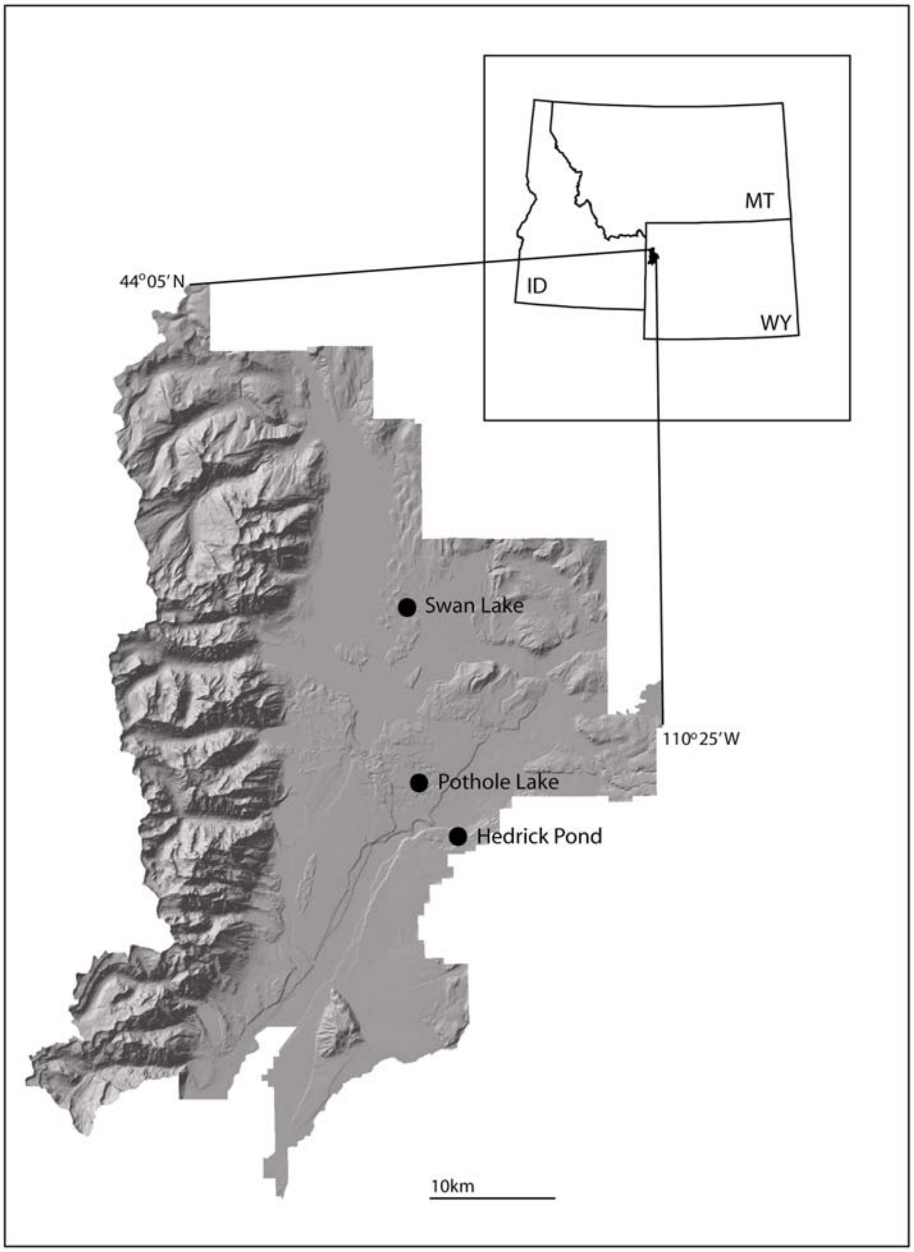

Figure 1: Location map of Grand Teton National Park, showing study sites.

Modern Vegetation and Geological Setting

The low-elevation forest near Hedrick Pond is dominated by *Pinus contorta* (all botanical nomenclature follows Shaw, 2000 and references therein) and also includes *Pseudotsuga menziesii*, *Abies lasiocarpa* (subalpine fir), *Picea engelmannii* (Englemann spruce). Areas of moist soil support *Populus tremuloides* (quaking aspen). Hedrick Pond lies on the border of sagebrush steppe, which is dominated by *Artemisia tridentata* (big sagebrush) and *Purshia tridentata* (antelope bitterbrush), and partially rimmed by a margin of riparian vegetation. Hedrick Pond itself is also partially covered by *Nuphar polysepalum* (Rocky Mountain pondlily). The mixed-forest surrounding Hedrick Pond supports a mixed-severity fire regime where fires occur between 30 and 70 years apart (Brown and Smith, 2000).

The sagebrush steppe that surrounds Pothole Lake consists of *Artemisia tridentata* and *A. longiloba* (little sagebrush). *Purshia tridentata* is also common on the sagebrush steppe. Many herbs grow among the shrubs, including members of Asteraceae (e.g. *Castilleja miniata*, *Helianthella uniflora*), Chenopodiaceae (e.g. *Atriplex patula*), Caryophyllaceae (e.g. *Cerastium arvense*),and Polemoniaceae (e.g. *Gilia aggregata*). In the western United States, fire-return intervals in *Artemisia* steppe are variable, with stand-replacing fires occurring every 10 to 70 years (Brown and Smith, 2000). Pockets of forest grow mainly on north-facing slopes in the Potholes area and are composed of *Pseudotsuga menziesii*, *Picea engelmannii*, and *Pinus contorta*. *Pinus flexilis* (limber pine) is present as isolated trees in the steppe. *Picea pungens* (blue spruce), *Picea engelmannii*, *A. lasiocarpa*, *Juniperus scopulorum* (Rocky Mountain juniper), *Populus* *trichocarpa* (black cottonwood), *Populus angustifolia* (narrowleaf cottonwood), and *Betula glandulosa* (dwarf birch) grow in the bottomlands of the Snake River and its tributaries.

Swan Lake is surrounded by closed forest dominated by *Pinus contorta*. *Abies lasiocarpa* and *Picea engelmannii* are also present in minor amounts with common groundcover species, such as *Geranium viscosissimum*, *Rosa woodsii*, and *Fragaria vesca*. *Nuphar polysepalum* is locally rooted in the bottom of Swan Lake, which is also rimmed by riparian vegetation including *Salix lasiandra* (whiplash willow). *Artemisia tridentata* grows in forest openings around Swan Lake. Lodgepole pine forests in the western United States support mixed-severity to high-severity fire regimes, and fires can occur every 30 to 300 years (Brown and Smith, 2000; Romme and Despain, 1989).

At higher elevations in the Teton and Gros Ventre ranges, conifer forests consist of *Abies lasiocarpa*, *Pseudotsuga menziesii*, *Pinus contorta*, *Pinus albicaulis* (whitebark pine), *Pinus flexilis*, and *Picea engelmannii*. A diverse suite of herbs grows in the subalpine meadows of the Teton Range. Upper treeline occurs at ca. 3000 m elevation, above which bare rock and alpine tundra are present (Mahaney and Spence, 1990).

The lakes in this study were formed during the Pinedale (Late Wisconsin, ca. 14,000 to 15,000 cal yr BP) glacial recession and are thus much older than 2000 years (Pierce and Good, 1992; Licciardi et al., 2005) [Note: “cal yr BP” means calendar years before present, with “present” set at AD 1950]. During the last glaciation, three major ice lobes fed glaciers in the Jackson Hole valley. The Snake River lobe advanced down the Snake River valley from the Yellowstone Plateau ice cap, the Pacific Creek lobe advanced southwest down the valley of Pacific Creek, and the Buffalo Fork lobe advanced west down the Buffalo Fork (Love et al., 2003). During the Hedrick Pond advance (ca. 15,000 cal yr BP; Pierce and Good, 1992), ice lobes entered Jackson Hole from the Snake River and Pacific Creek valleys. The maximum position of the Hedrick Pond glacial advance left terminal moraines running east-west in the vicinity of Hedrick Pond. Hedrick Pond itself was formed when a block of Hedrick Pond ice was buried by recessional outwash (K. Pierce, written comm., 2006; Pierce and Good, 1992). During the Jackson Lake recession (ca. 14,000 cal yr BP), the ice margin had receded from the Hedrick Pond advance position and remained stationary around the present-day southern margin of Jackson Lake. The Potholes channelway was one of the several prominent outwash channels during this glacial recession. Blocks of glacial ice from the Hedrick Pond advance were buried by this outwash, and when they melted, Pothole Lake was formed in a kettle depression. Farther to the north, Swan Lake basin lies in a glacial scour depression created when the Snake River glacial lobe retreated north from its maximum position and created aligned furrows and ridges in the Colter Bay area (Pierce and Good, 1992).

METHODS

Field Methods

Lakes were cored with a 5-cm-diameter modified Livingstone square-rod piston sampler (Wright et al., 1983) from the deepest portion of each lake. Pothole Lake and Swan Lake were cored from an anchored raft in June 2005. Cores were taken from Hedrick Pond from the ice surface in January 2005. Cores were extruded in the field, wrapped in plastic wrap and aluminum foil and taken to the Montana State University (MSU) Paleoecology lab where they were refrigerated. In addition, short sediment cores were taken from each site with a 7-cm-diameter Klein piston corer to recover the mud-water interface and the upper half-meter of sediment. Each short core was sub-sampled in the field at 1-cm intervals, and samples were stored in Whirl-pac bags and refrigerated.

Laboratory Methods

Loss-on-ignition (LOI) is used to determine the percentage of organics and inorganics in sediment, and provides a proxy of lake productivity (Dean, 1974). LOI determinations were undertaken with 1-cm^3 samples at contiguous 1-cm intervals to a depth of 20 cm in the Hedrick Pond short core and every other cm to 60 cm depth. In the long core, samples were taken every 5 cm. In the Pothole Lake core contiguous 1-cm intervals were sampled to a depth of 14 cm, and at 2-cm intervals to 66 cm depth. In the Swan Lake short core contiguous 1-cm intervals were sampled to a depth of 8 cm, and at

5-cm intervals in the long core. Samples were dried at 90^{o}C for 24 hours, and ashed at 550^{o}C to burn off organics and then 900^{o}C to burn off most carbonates for 2 hours each. Weight loss after heating was used to calculate percentages of dry weight, organic content, and carbonate content, respectively (Dean, 1974).

Magnetic susceptibility, an indicator of deposition of mineral soil or fire-created detrital magnetite or maghemite (Thompson and Oldfield, 1986), was measured with a Bartington MS2 magnetic susceptibility cup sensor and ring sensor. Contiguous 10 cm^3 samples were measured in the long and short cores from the Hedrick Pond and Swan Lake with the cup sensor, and 10 cm^3 samples were analyzed at 2-cm intervals with the ring sensor in the Pothole Lake core. MS units were expressed as cgs x 10^{-6}.

Charcoal

Macroscopic charcoal analysis was performed on contiguous 1-cm interval samples to reconstruct the local fire history for each site (e.g. Long et al., 1998). Charcoal processing followed modified sieving methods described by Whitlock and Larsen (2001). Samples of 3 cm^3 (Hedrick Pond and Swan Lake) and 4 cm^3 (Pothole Lake) were soaked in a solution of 5% sodium metaphosphate and 6% bleach for 24 hours and washed through nested sieves (mesh size 250 and 125 μ). Charcoal particles greater than 125μ in size represent local fire activity (Whitlock and Larsen, 2001). Residues were placed in a gridded Petri dish and identified under a stereoscope at magnifications of 120x and 250x. Charcoal counts of two size fractions (>250μ and >125μ) were combined and divided by sample volume to calculate charcoal concentrations (particles cm^{-3}). Concentrations and sedimentation rates were interpolated to pseudo-annual values and then binned in 10-yr-long intervals. Charcoal accumulation rates (CHAR; particles cm^{-2} $year^{-1}$) were calculated by dividing charcoal concentration by the deposition time (yr cm^{-1}). Interpolation of concentration values to pseudo-annual values followed by binning and calculation of CHAR preserves the total number of particles accumulated over time (CHAPS; Bartlein, unpub. software).

The development of a fire history from the charcoal data followed the decomposition approach of Long et al. (1998). Time series of CHAR data were divided into two components. Background CHAR, or the low-frequency slowly varying component, was determined using a locally-weighted (moving) average through the time series, where the width of the weight function (window width) controlled the smoothness of the curve. Variations in background CHAR were interpreted as changes in regional fire activity, charcoal stored in the watershed, or changes in the biomass of the surrounding area (Long et al., 1998; Whitlock and Larsen, 2001; Marlon et al., 2006). For all sites in this study, a window width of 500 years was used to calculate background CHAR levels. This window width has become a standard for Greater Yellowstone Ecosystem (GYE) charcoal studies, and it produced a background signal that followed the broad frequency trends in the data (Marlon et al., 2006). Because macroscopic (>125µ) charcoal represents local fire activity (Whitlock and Larsen, 2001), positive deviations of CHAR above the background component are considered to represent charcoal accumulation related to a single fire or episode of fires in the area surrounding the study site during the time span represented by a sample. These peaks, or the high-frequency component of CHAR, were identified as those levels that exceeded a prescribed threshold ratio of total CHAR to background CHAR. A threshold ratio of 1.0, for example, identifies all CHAR values that exceed the background CHAR level as fire episodes. A fire episode begins when the threshold ratio is first exceeded and ends when CHAR values drop back below the ratio, usually lasting several decades at the sites in this study. A threshold ratio of 1.15 was used to identify peaks in this study because it produced charcoal peaks that corresponded in time with recent fires in the vicinity of each site (Loope, 1974; Grand Teton National Park Fire Management Office, 2006). This ratio also did not pick up additional spurious peaks that were not associated with local fire events.

Pollen

Pollen samples were taken at 4- to 6-cm intervals (Hedrick Pond), 4-cm intervals (Pothole Lake), and 3-cm intervals (Swan Lake). Based on our age models, this produced a vegetation history at 30-year intervals. Pollen samples were processed following modified methods of Faegri et al. (1989) with the use of Schulze’s solution in place of acetolysis (e.g., Doher, 1980). Pollen preparations were mounted in silicone oil and examined under magnifications of 400x and 1000x. Identifications were based on a comparison of published atlases and keys (e.g., Kapp et al., 2000; Moore and Webb, 1978). Whenever the distal membrane was preserved, pine pollen was separated into diploxylon-type (*Pinus contorta*) and haploxylon-type (*P. flexilis, P. albicaulis*). Pine pollen grains without a distal membrane were identified as Undifferentiated *Pinus*, which was assumed to contain the same proportions of haploxylon-type and diploxylon-type pine as the fraction that could be identified. *Picea* grains were probably from *P. engelmannii*, with a smaller component of *P. pungens* (which occurs near the Snake River). *Alnus* grains were assigned to *A. incana* (mountain alder) which grows in moist meadows and lowlands. Grains that could not be identified were designated as Unknown; grains that were deteriorated, corroded, or severely broken were designated as Degraded.

Percentage data of terrestrial taxa were tallied based on the sum of all terrestrial taxa. Percentages of aquatic taxa were based on the sum of all terrestrial, aquatic and wetland taxa. A “spike” of *Lycopodium* spores of known concentration was added to each sample to calculate pollen concentration. Concentration data were divided by the calculated deposition time (yr cm^{-1}) of each sample to calculate pollen accumulation rates (PAR; pollen cm^{-2} yr^{-1}).

RESULTS

Lithology and Chronology

At Hedrick Pond, a 137-cm-long core was recovered from beneath 4.70 m of water (Figure 2a). The sediments consisted of homogeneous fine detritus gyttja. Two AMS ^{14}C dates (Table 1) were obtained from 69 and 137 cm depth, and radiocarbon ages were converted to calendar years using the CALIB program of Stuiver et al. (2005). Fourteen ^{210}Pb dates were obtained from the top 14 cm of the core (Table 2). The AMS ^{14}C and ^{210}Pb dates were fitted with a 3^{rd}-order polynomial age-depth model (Figure 3). The base of the core was dated at 2182 ± 28 cal yr BP.

The organic content of the Hedrick Pond core varied between 40 and 60% (Fig. 2a), and $CaCO_3$ content was <10%. Magnetic susceptibility was very low through the core and varied between -1 and 0 cgs x 10^{-6}. Variations in magnetic susceptibility were not associated with those in charcoal concentration, as was found in Yellowstone (e.g. Millspaugh et al., 2000), and this lack of relationship suggests no strong connection between fires and erosion events.

Table 1: Uncalibrated radiocarbon dates, calibrated ages, and age models

Depth (m)[a]	Uncalibrated ^{14}C age (^{14}C yr BP)	Calibrated age (cal yr BP) with 2 sigma range[b]	Material dated	Lab number[c]
Hedrick Pond				
0.69	700 ± 40	575, **666**, 580, 664, 706, 720 (559-721)	Conifer needle	LL119626
1.37	2209 ± 39	**2182**, 2247, 2301, 2236 (2140-2333)	Unidentified leaf	AA63992
Pothole Lake				
0.33	290 ± 40	314, 364, **400.5**, 160.5, 376 (155-467)	Unidentified leaf	LL119627
0.48	1090 ± 50	**986.5**, 1039, 1008.5, 1121.5, 1164.5 (924-1167)	Unidentified leaf	LL119625
Swan Lake				
0.70	455 ± 35	**511.5**, 344.5, 501.5 (343-541)	Wood bark	LL119624

Age Models (including ^{210}Pb dates)[d]

Hedrick Pond Age (cal yr BP): $-0.0002 \cdot \text{depth}^3 + 0.1212 \cdot \text{depth}^2 + 2.9296 \cdot \text{depth} - 56.605$ ($r^2 = 0.999$)

Pothole Lake Age (cal yr BP): $0.0038 \cdot \text{depth}^3 + 0.2122 \cdot \text{depth}^2 + 2.6524 \cdot \text{depth} - 55.009$ ($r^2 = 0.999$)

Swan Lake (0 – 59 cal yr BP)[e]: $0.0263 \cdot \text{depth}^4 - 0.3565 \cdot \text{depth}^3 + 1.2818 \cdot \text{depth}^2 + 1.7373 \cdot \text{depth} - 52.824$ ($r^2 = 0.9987$)

Swan Lake (59 – 550 cal yr BP)[f]: $8.1441 \cdot \text{depth} - 58.585$

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[a] Depth below mud surface.

[b] ^{14}C ages derived from CALIB 5.0.2 calibration curves (Stuiver et al., 2005). In some cases, multiple ages were possible if the sample crossed multiple points along the calibration curve. In these cases, the age with the greatest area under the probability curve was used in the age model (bolded age). The 2 sigma age range is given in parentheses.

[c] AA – University of Arizona AMS Facility; LL – Lawrence Livermore National Laboratory

[d] ^{210}Pb dates were adjusted for the 55 years (the cores were taken in 2005) since 1950 AD in order to compare them with the calibrated radiocarbon dates.

[e] The Swan Lake age model between 0 and 59 cal yr BP was based on ^{210}Pb dates only (Table 2).

[f] The Swan Lake age model prior to 59 cal yr BP was based on calibrated ^{14}C ages and only the oldest ^{210}Pb date.

Table 2. Short core ^{210}Pb concentrations and age determinations[a]

Depth (cm)[b]	^{210}Pb dpm g^{-1}	Age (yr AD)
Hedrick Pond		
0-1	67.57	2003
1-2	43.10	2001
2-3	38.64	1999
3-4	28.38	1997
4-5	33.79	1994
5-6	34.70	1991
6-7	30.98	1987
7-8	29.74	1984
8-9	14.88	1980
9-10	19.45	1977
10-11	12.90	1973
11-12	21.74	1968
12-13	17.16	1954
14-15	7.44	1919
Pothole Lake		
0-1	47.67	2003
1-2	28.13	2001
2-3	31.81	1999
3-4	31.01	1996
4-5	36.03	1992
5-6	32.68	1986
6-7	21.73	1981
7-8	18.83	1976
8-9	15.31	1970
9-10	12.62	1965
10-11	12.27	1955
12-13	8.93	1927
Swan Lake		
0-1	72.02	2003
1-2	60.61	2000
2-3	36.02	1996
3-4	22.04	1994
4-5	22.18	1992
5-6	16.83	1991
6-7	14.81	1988
7-8	10.18	1986
8-9	28.09	1983
9-10	26.27	1972
10-11	16.16	1950
11-12	20.62	1919

[a] Concentration age determinations provided by Dr. James Budahn at the U.S. Geological Survey, Denver, CO.

[b] Depth below mud surface.

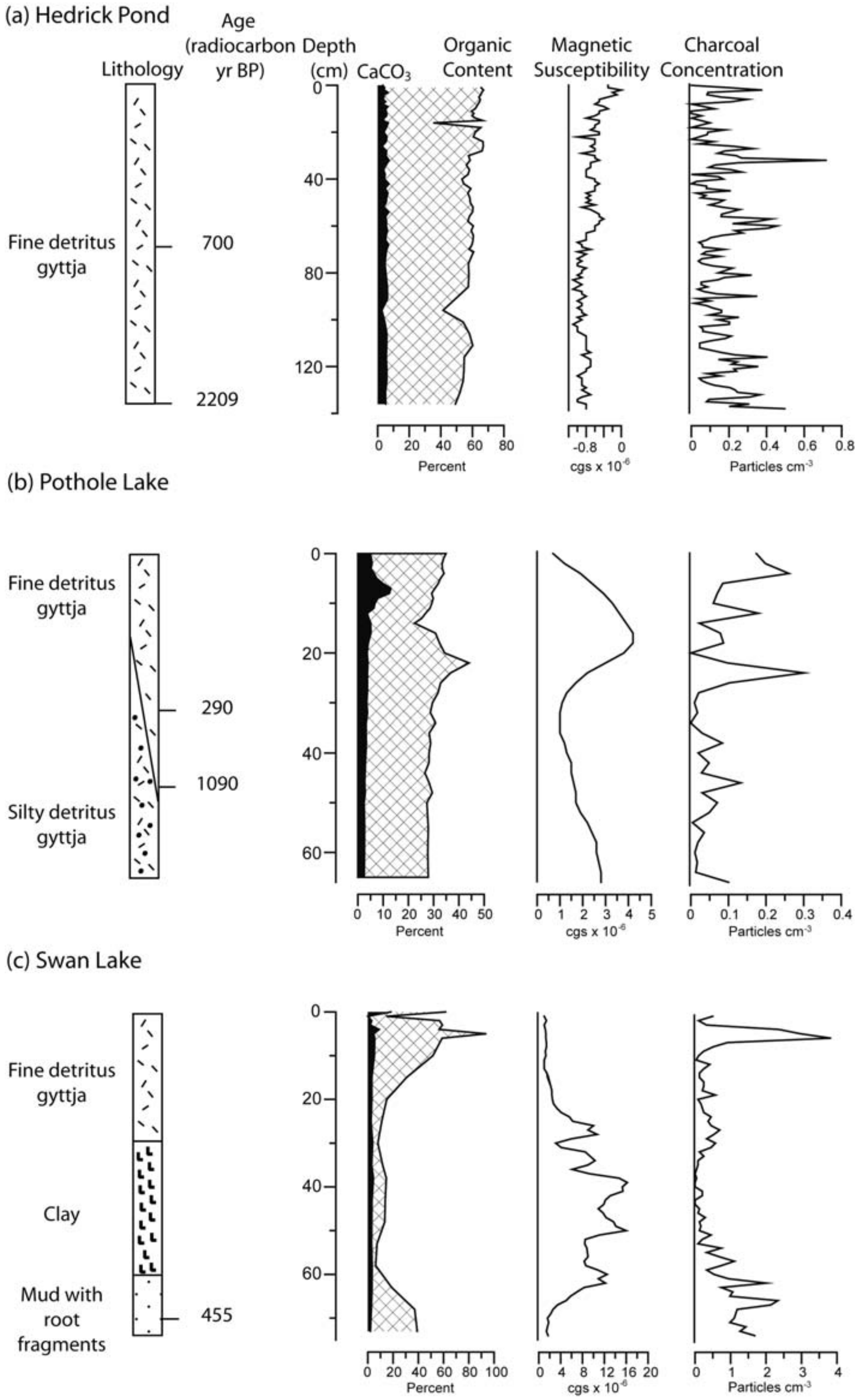
(a) Hedrick Pond
Lithology
Age (radiocarbon yr BP)
Depth (cm)
CaCO3
Organic Content
Magnetic Susceptibility
Charcoal Concentration
Fine detritus gyttja
700
2209
0
40
80
120
0 20 40 60 80
Percent
-0.8 0
cgs x 10-6
0 0.2 0.4 0.6 0.8
Particles cm-3
(b) Pothole Lake
Fine detritus gyttja
290
1090
Silty detritus gyttja
0
20
40
60
0 10 20 30 40 50
Percent
0 1 2 3 4 5
cgs x 10-6
0 0.1 0.2 0.3 0.4
Particles cm-3
(c) Swan Lake
Fine detritus gyttja
Clay
Mud with root fragments
455
0
20
40
60
0 20 40 60 80 100
Percent
0 4 8 12 16 20
cgs x 10-6
0 1 2 3 4
Particles cm-3

Figure 2: Core lithology, carbonate and organic content, magnetic susceptibility and raw charcoal concentration for (a) Hedrick Pond, (b) Pothole Lake and (c) Swan Lake.

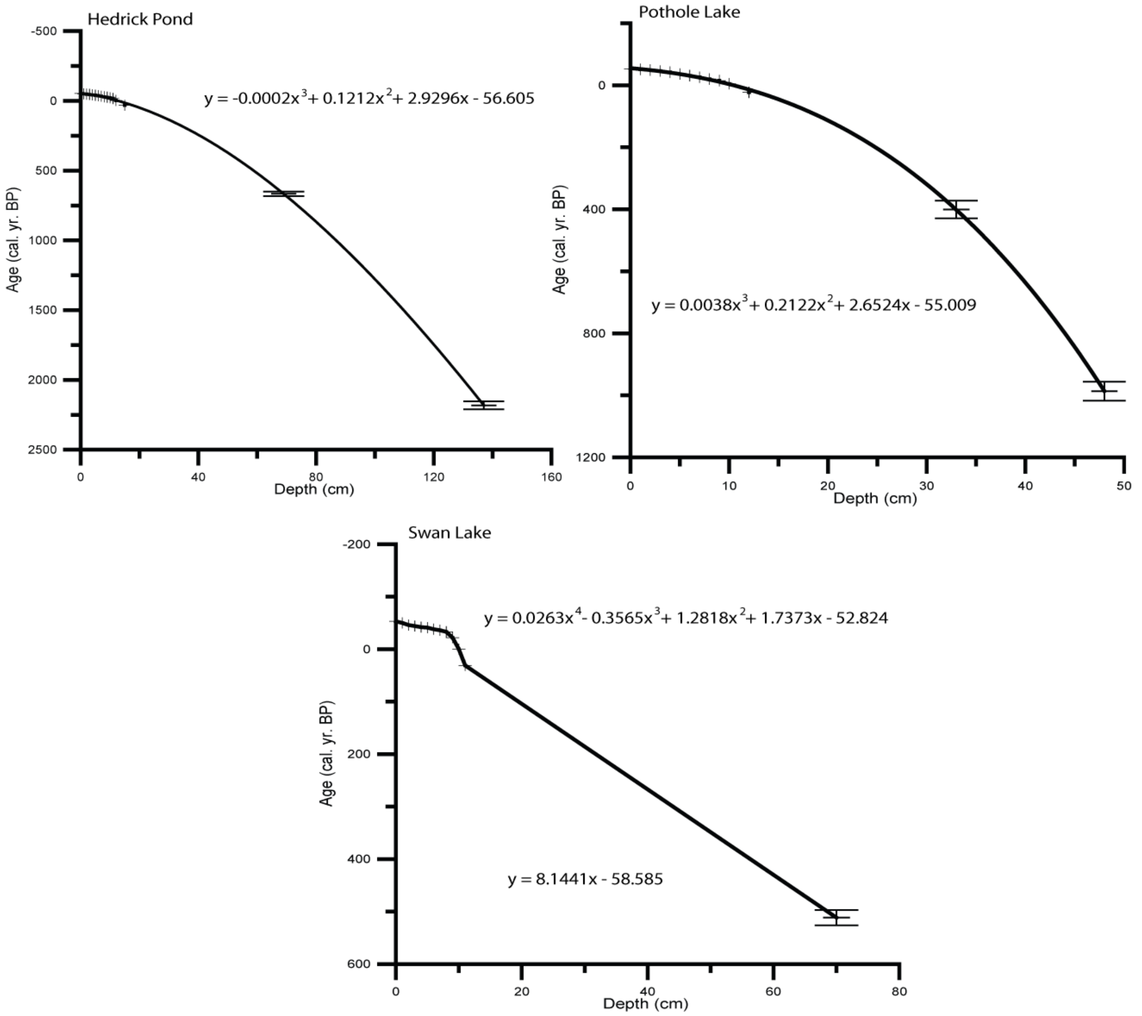

Figure 3: Calibrated age vs. depth curves for each site including ^{210}Pb and ^{14}C dates. Calibrated radiocarbon dates show 2 sigma error bars. See Table 1 and Table 2 for age determinations and age models.

At Pothole Lake, a 66-cm-long short core was recovered from 2.10 m of water (Figure 2b). The core consisted of an upper unit of fine detritus gyttja that graded downward to silty detritus gyttja (17-50 cm depth) and firm organic silty clay at the base. The bottom unit at 66 cm depth had a crumbly structure with fine rootlets and appeared to be a buried soil. Two AMS ^{14}C dates (Table 1) were obtained from 33 and 48 cm depth.

Twelve ^{210}Pb dates were obtained from the top 12 cm of the core (Table 2). A 3rd-order polynomial age-depth model was fitted to the AMS ^{14}C and ^{210}Pb dates. The base of the core was extrapolated to 2136 cal yr BP.

The organic content of the Pothole Lake core varied between 25 and 40% (Fig. 2b). The $CaCO_3$ content was <10% except for a peak to 15% at 8 cm depth. The lowest organic content and a peak in magnetic susceptibilitywere associated with clay minerals in the core between 15 and 25 cm depth. Magnetic susceptibility increased towards the bottom of the core, suggesting more input of allochthonous inorganic material to the lake. The silty detritus gyttja at the base of the core along with the higher magnetic susceptibility indicated a period of allochthonous sedimentation before 1090 cal yr BP. The Pothole Lake core ended in a buried soil with root fragments that was not processed in this study. The occurrence of a soil strongly suggests a dry period when there was no standing water in Pothole Lake prior to about 1000 cal yr BP. Charcoal concentration in the Pothole Lake core was not correlated with magnetic susceptibility.

At Swan Lake, a 73-cm-long core was recovered from 3.30 m of water (Figure 2c). The core consisted of fine detritus gyttja from 0 to 29 cm depth, underlain by gray-brown clay from 29 to 60 cm depth, and dark brown mud with root fragments from 60 to 73 cm depth. An AMS ^{14}C date (Table 1) from the mud unit had an age of 511.5 cal yr BP (+/- 14.5). Twelve ^{210}Pb dates were obtained from the top 12 cm of the core (Table 2). The ^{210}Pb dates and the AMS ^{14}C date were incongruent. Therefore, a 4th-order polynomial model based on the ^{210}Pb dates was used for the top 12 samples, and a linear model based on the oldest ^{210}Pb date and the AMS ^{14}C date was used for the remainder of the core. This age-versus-depth model provided consistent dates for known fire events around Swan Lake based on fire-scar tree-ring records (Loope, 1974). The base of the Swan Lake core was linearly interpolated to 536 cal yr BP.

Organic content in the Swan Lake core varied between 10 and 90% (Fig. 2c). $CaCO_3$ content was <10%. A significant drop in organic content between 20 and 60 cm depth was associated with a clay layer. This clay layer was also correlated with a peak in magnetic susceptibility. The clay suggests a period of less organic input to the Swan Lake system. During the past 2000 years the Pilgrim Creek delta has built at a rate of about 0.5 m kyr^{-1} (Pierce et al., 1998), closing the basin that contains Swan Lake. Perhaps large flood events during the last 2000 years spilled into Swan Lake from the Pilgrim Creek drainage, depositing clay.

Charcoal Records

The average resolution of the Hedrick Pond charcoal record was approximately 17.5 years cm^{-1}. Background CHAR (Figure 4) was ~0.2 particles cm^{-2} yr^{-1} between 2150 and 1500 cal yr BP and decreased to ~0.13 particles cm^{-2} yr^{-1} between 1500 and 750 cal yr BP. In the last 750 cal yr, background CHAR increased to ~0.2 particles cm^{-2} yr^{-1} and subsequently decreased to ~0.1 particles cm^{-2} yr^{-1}. Peaks in all records are assumed to represent decades of higher-than-average local fire activity. Charcoal peaks in the last 500 cal yr BP were dated from -30 to -50 cal yr BP (AD 1980-2000), 100 to 170 cal yr BP (AD 1780-1850), 190 to 200 cal yr BP (AD 1740-1750), and 400 to 410 cal yr BP (AD 1540-1550). Earlier peaks occurred at 450 to 550, 800 to 890, 1020 to 1040, 1160 to 1180, 1210 to 1230, 1250 to 1280, 1380 to 1420, 1570 to 1610, 1640 to 1730, 1910 to 2000, 2070 and 2110 to 2120 cal yr BP.

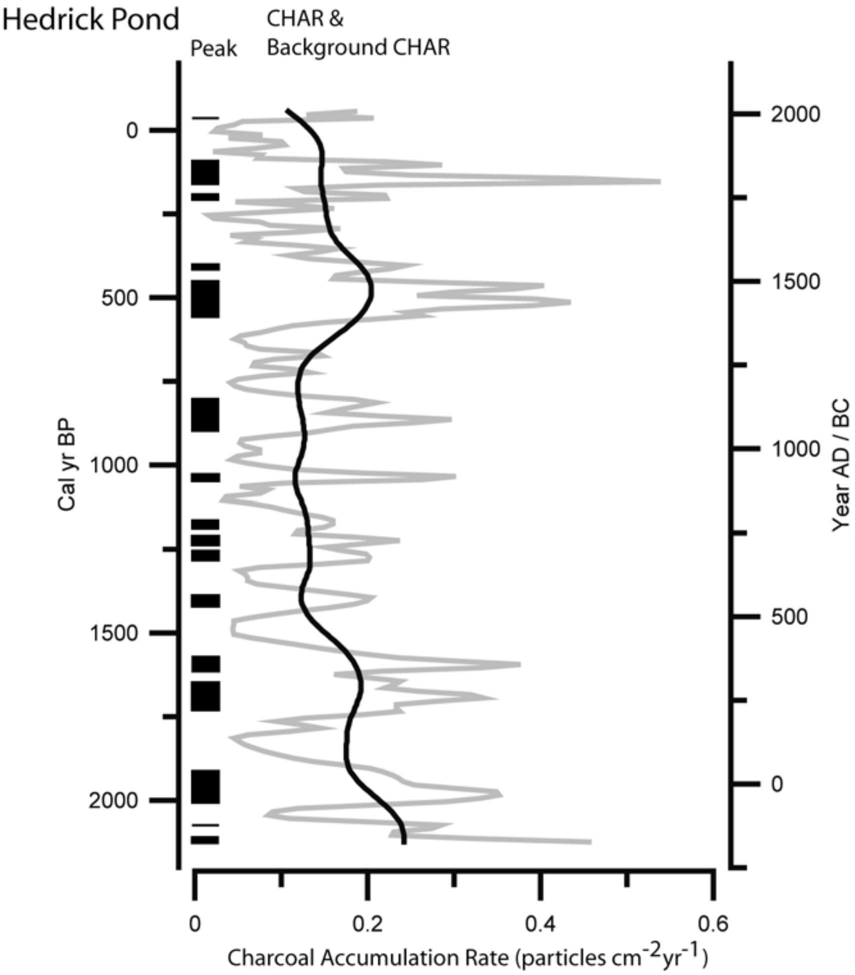

Figure 4: Charcoal record of the last 2100 years at Hedrick Pond. Accumulation rates were decomposed into background (the slowly varying curve overlying the accumulation rate curve (window width = 500 yr). Decades with higher-than-average fire (charcoal accumulation peaks above the threshold value) are marked by black rectangles on the left side of graph (threshold value = 1.15). Peaks were graphed as the entire time that CHAR exceeds the threshold ratio.

At Pothole Lake, the deposition time for each sample was approximately 27.2 years cm^{-1}. The background CHAR (Figure 5) was low at ~0.04 particles cm^{-2} yr^{-1} from

1250 cal yr BP to present. Charcoal peaks in the last 500 cal yr BP were dated from -30 to -50 cal yr BP (AD 1980-2000), 140 to 190 cal yr BP (AD 1810-1760), 280 to 300 cal yr BP (AD 1650-1670), and 380 to 400 cal yr BP (AD 1550-1570). Earlier peaks occurred at 500 to 560, 650 to 690 and 840 to 940 cal yr BP, however, the data prior to 1000 cal yr BP is unreliable.

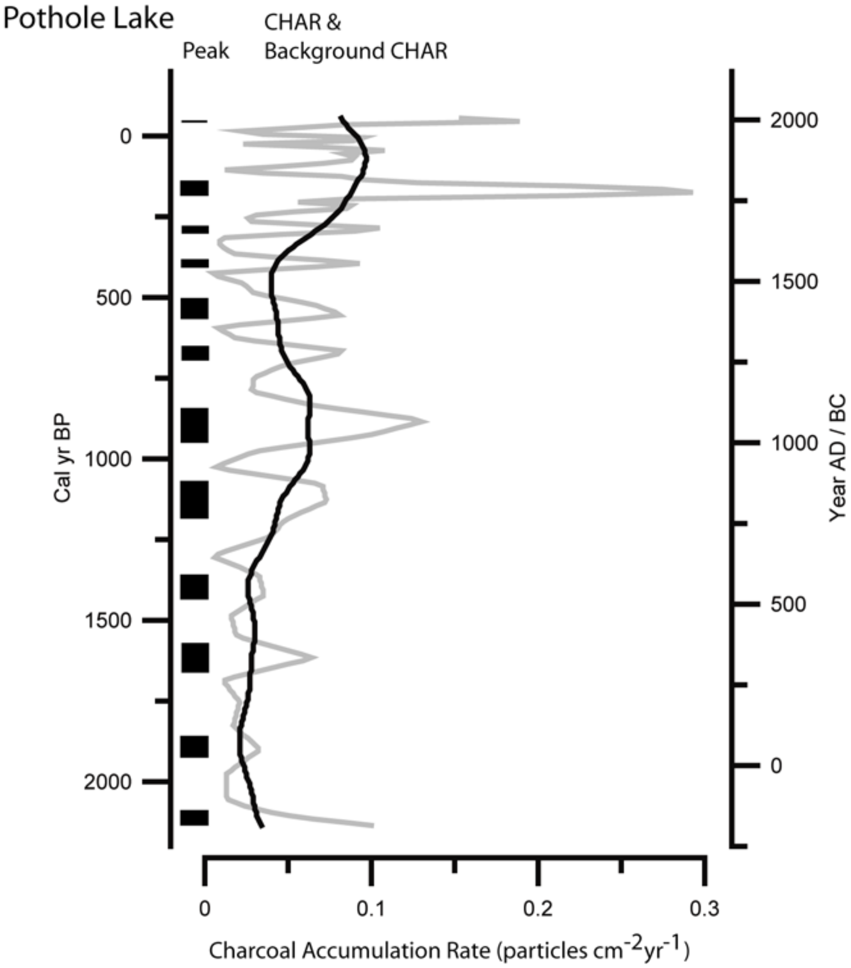

Figure 5: Charcoal record of the last 2100 years at Pothole Lake (see Fig. 4 for explanation). The first 1000 years of data are unreliable and not used in this study. They are shown here for completeness.

The Swan Lake charcoal record had a sampling resolution of approximately 9.6 years cm^{-1}. Background CHAR (Figure 6) levels from 550 to 200 cal yr BP were ~1 particle cm^{-2} yr^{-1}. Background CHAR decreased to ~0.3 particles cm^{-2} $year^{-1}$ in the last 200 cal years. Charcoal peaks were dated from -30 to -50 cal yr BP (AD 1980-2000), 30 cal yr BP (AD 1920), 80 to 90 cal yr BP (AD 1860-1870), 120 to 180 cal yr BP (AD 1830-1770), 390 to 400 cal yr BP (AD 1550-1560), 430 to 490 cal yr BP (AD 1520-1460), and 520 to 530 cal yr BP (AD 1420-1430).

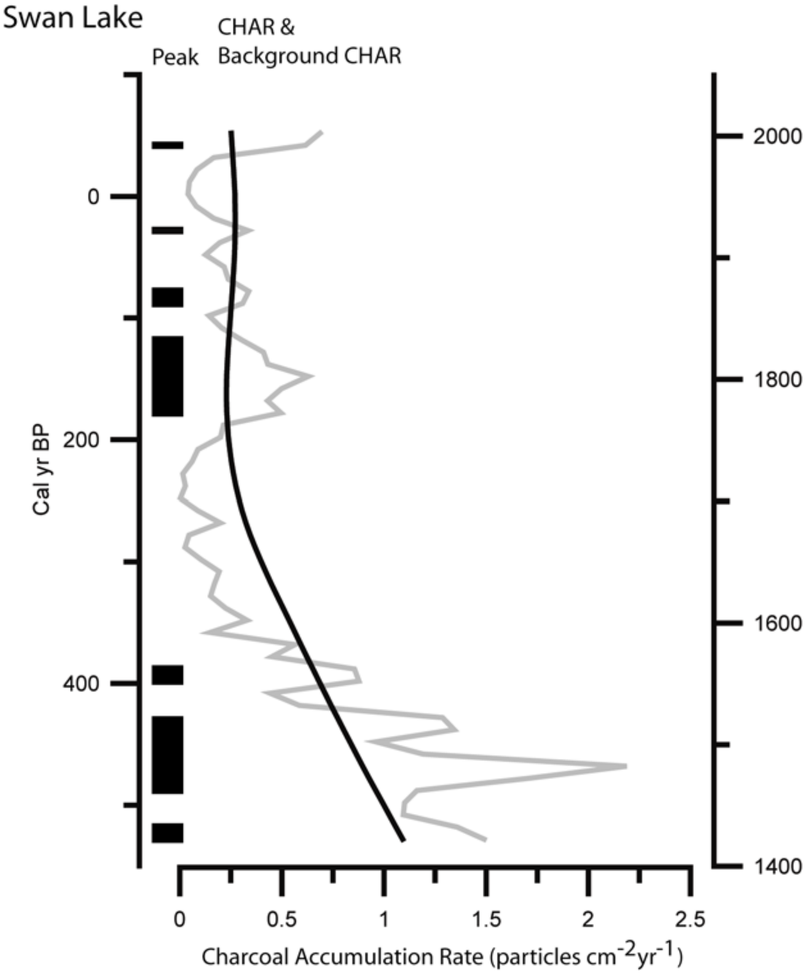

Figure 6: Charcoal record of the last 550 years at Swan Lake (see Fig. 4 for explanation).

Pollen Records

Hedrick Pond Record

The Hedrick Pond pollen record was divided into three zones determined using CONISS, a constrained cluster analysis (Grimm, 1987; Figure 7):

Zone HED-1 (82-137 cm depth; ca. 850-2130 cal yr BP) featured high percentages of total *Pinus*, *Artemisia* and Poaceae (grass family). Zone HED-1 is dominated by *Pinus contorta*-type pollen, which is consistent with modern pollen from *P. contorta* forests in the GYE (Whitlock, 1993). *Picea*, *Abies*, Chenopodiineae (goosefoot and amaranth families), and *Ambrosia*-type (ragweed) were present in moderate amounts. Total PAR (pollen accumulation rate) averaged 1500 grains cm^{-2} yr^{-1}, which is low for present-day *Pinus contorta* forest (Fall, 1992). *Artemisia* was between 20 and 30%; these values are higher than in present-day *P. contorta* forests in the region (Whitlock, 1993), which suggests that Hedrick Pond was at the ecotone between lodgepole pine forest and *Artemisia* steppe at this time.

Zone HED-2 (20-82 cm depth; 50-850 cal yr BP) was characterized by increasing total *Pinus* from 55 to 84% and decreasing *Artemisia* from 24 – 10%. *P. flexilis*-type decreased towards the top of this zone while *P. contorta*-type and total *Pinus* increased. *Picea* occurred at its highest percentages but still in low values (<4%). *Abies*, *Salix* (willow), and *Ambrosia*-type pollen were present in small amounts (<2%). Poaceae percentages decreased in the middle of the zone (ca. 450 cal yr BP) to ~2% and increased

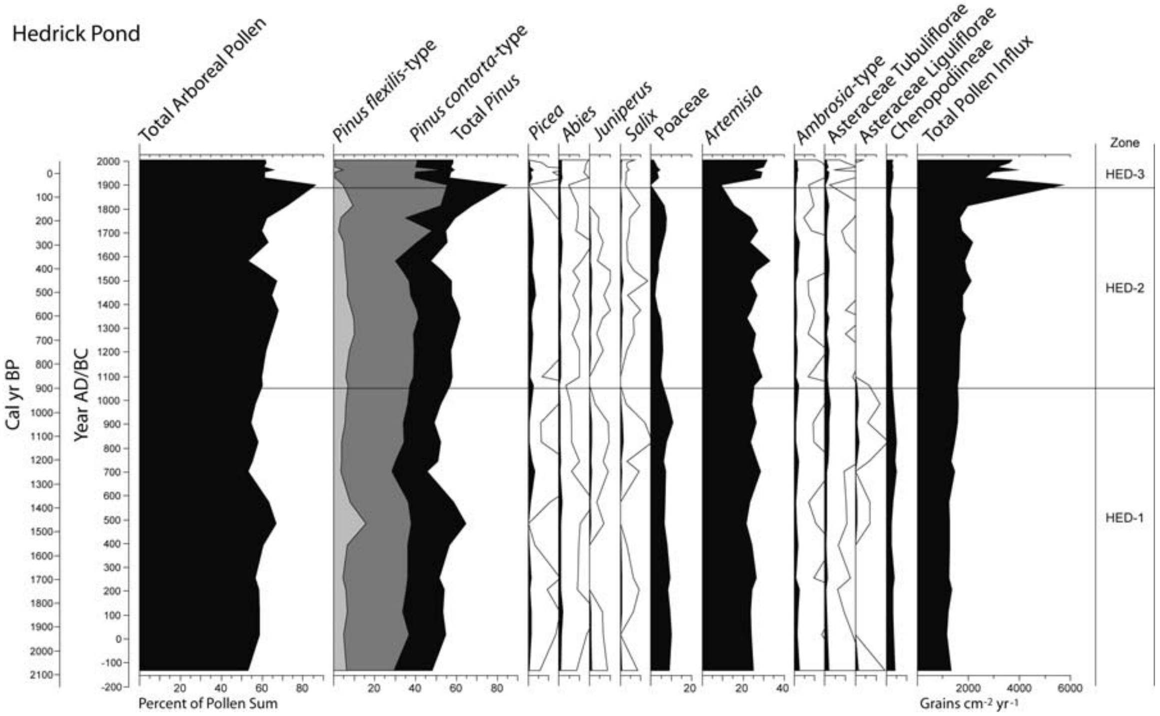

Figure 7: Pollen percentages and total pollen influx for Hedrick Pond. Outlined area is 10x exaggeration.

again to ~7% towards the top of the zone. *Juniperus* (juniper) pollen was present at the beginning of this zone (up to 1%) and dropped out at ca. 180 cal yr BP. Total PAR increased during this zone ending in a peak (ca. 4850 grains cm^{-2} yr^{-1}). The combination of *Pinus contorta*-type, *Picea*, and *Artemisia* is consistent with the modern pollen assemblages from lodgepole pine forest (Whitlock, 1993). The decrease in *Artemisia* percentages and rise in total *Pinus* percentages at the top of the zone was most likely due to closing of the forest around the site.

Zone HED-3 (0-20 cm depth; present-50 cal yr BP; AD 2006-1900) featured a drop in total *Pinus* percentage from 84 to 58% and a resurgence of *Artemisia* from 10 to 32%. *Picea*, *Abies*, and Poaceae percentages increased in the middle of this zone. Total

PAR increased in this zone to 3700 grains cm^{-2} yr^{-1}. The recent resurgence of *Artemisia* in the Hedrick Pond record was most likely caused by forest clearance in the last century. The assemblage is similar to pollen assemblages from both modern steppe and *Pinus contorta* forest, which is consistent with Hedrick Pond's ecotonal position at present.

Pothole Lake Record

The Pothole Lake pollen record was divided into three zones (Figure 8).

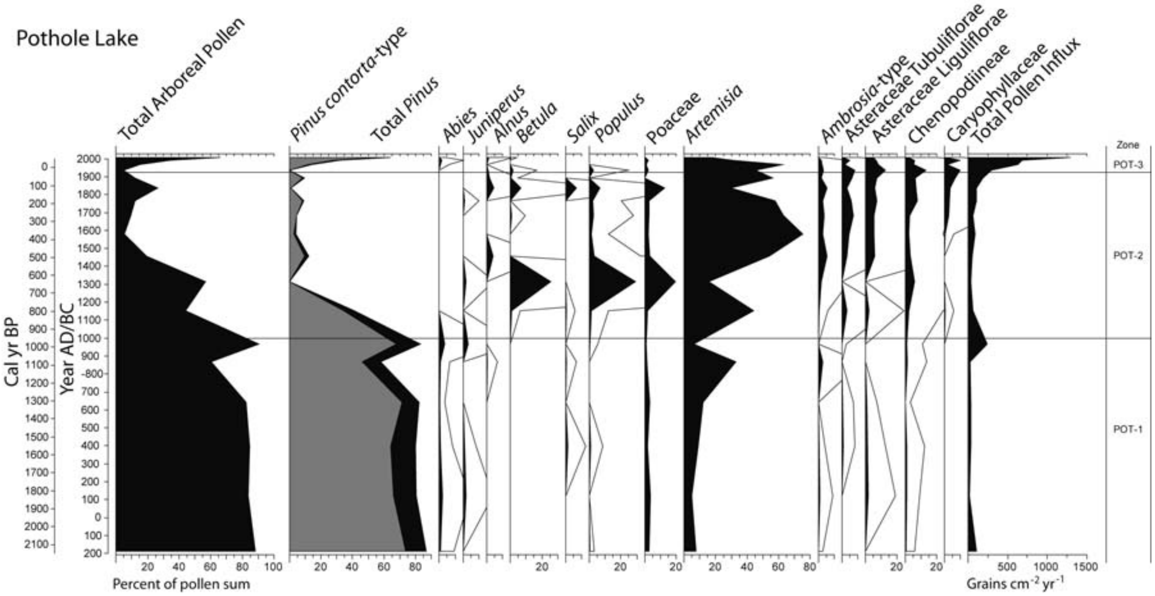

Figure 8: Pollen percentages and total pollen influx for Pothole Lake. Outlined area is 10x exaggeration

Zone POT-1 (48-66 cm depth; 980-2136 cal yr BP) was characterized by high percentages of total *Pinus* (ca. 80%) and low percentages of Poaceae and *Artemisia* (<12% and <4% respectively). Low percentages (<3%) of *Abies*, *Juniperus*, *Salix*, and *Populus tremuloides*-type made up the other arboreal taxa in this zone. Total PAR was very low during this zone (average 500 grains cm^{-2} yr^{-1}), which is typical of present-day alpine tundra (Birks and Birks, 1980).

The silty detritus gyttja and crumbly silts of Zone POT-1 indicate that Pothole Lake was wet only intermittently during this period. The pollen data support this interpretation. Most of the pollen grains were degraded, including pine pollen, which is characteristically robust (Faegri et al., 1989). The abundance of pine in this zone is likely a result of the degradation of other more delicate pollen types. The very low PAR is also indicative of a sub-aerial environment. Because the pollen data were not considered a reliable record of the vegetation, Zone POT-1 was not considered further.

Zone POT-2 (16-48 cm depth; 55-980 cal yr BP) began with decreasing percentages of total *Pinus* (80 to 40%) and increasing percentages of *Artemisia* (12 to 44%). *Pinus* then declined to very low values (<10%) and *Artemisia* became dominant. *Abies* values declined to zero in the middle of this zone and Poaceae values contributed to between 2 and 20%. Pollen of *Alnus*, *Betula*, and Caryophyllaceae first appeared in very low amounts and increased towards the top of Zone POT-2. Other arboreal pollen taxa in this zone were *Juniperus* (to 2%) and *Populus tremuloides*-type (to 29%). *Ambrosia*-type, other Asteraceae Tubuliflorae, Asteraceae Liguliflorae and Chenopodiineae pollen were all present in small amounts (3 to 8%). Total PAR was higher than in zone POT-1 (average 880 grains cm^{-2} yr^{-1}), which is consistent with values for sagebrush steppe in Idaho and Wyoming (Fall, 1992). The high percentages of *Artemisia* are consistent with modern pollen samples from the steppe communities in the GYE (Whitlock, 1993).

Poaceae is present in amounts between 4 and 8% in modern steppe samples (Whitlock, 1993), which agrees with the percentages of Poaceae in Zone POT-2 (2 to 20%).

Zone POT-3 (0-16 cm depth; present-55 cal yr BP; AD 2006-1895) featured an increase in total *Pinus* towards the present and a reappearance of *Abies* pollen. *Artemisia* values declined towards present from 62 to 18%, as did *Ambrosia*-type (3 to 0.4%), other Asteraceae Tubuliflorae (8 to 1.2%), Asteraceae Liguliflorae (12 to 4.8%), Chenopodiineae (13 to 2%) and Caryophyllaceae (10 to 1.2%). The uppermost samples had the highest PAR of the record at ca. 13,000 grains cm^{-2} yr^{-1}. The increase in total *Pinus* at the top of the Pothole Lake record is coincident with an encroachment of lower treeline into steppe and grassland environments that has occurred in the last century in the western United States (Veblen and Lorenz, 1991). Pothole Lake is not a forested site today, but more pine pollen may be entering the lake from trees now growing closer to the site. Pothole Lake is surrounded by *Artemisia* steppe, and the abundance of *Artemisia* and other steppe taxa, such as *Ambrosia*-type, Poaceae and other Asteraceae, is consistent with modern steppe pollen from the region (Whitlock, 1993).

Swan Lake Record

The Swan Lake pollen record was divided into three zones using CONISS (Figure 9):

Zone SW-1 (53-73 cm depth; ca. AD 1575-1430) was dominated by *Artemisia* (average 55%), with low percentages of *Pinus* (average 30%), largely from *P. contorta*-type. Chenopodiineae pollen was well represented (up to 16%) and decreased to 3%

towards the top of this zone. *Picea* (<2%), *Abies* (<2%), *Alnus* (<3%) and *Salix* (<12%) were present in low amounts. *Ambrosia*-type reached its highest amounts (up to 4%) during this zone, and Asteraceae Liguliflorae was present in trace amounts. Total PAR was average for this zone (ca. 8000 grains cm^{-2} yr^{-1}), which is consistent with other steppe areas in the western United States (Fall, 1992). Percentages of *Artemisia* in Zone SW-1 are higher than average for modern steppe in the GYE (Whitlock, 1993). Possibly, *Artemisia* shrubs were denser than in the modern steppe. *Alnus* and *Salix* grow in wetland environments at present, and it is possible that a broader riparian area surrounded Swan Lake before AD 1575. The high percentages of *Artemisia* in Zone SW-1 suggest that the site was surrounded by steppe vegetation (Whitlock, 1993).

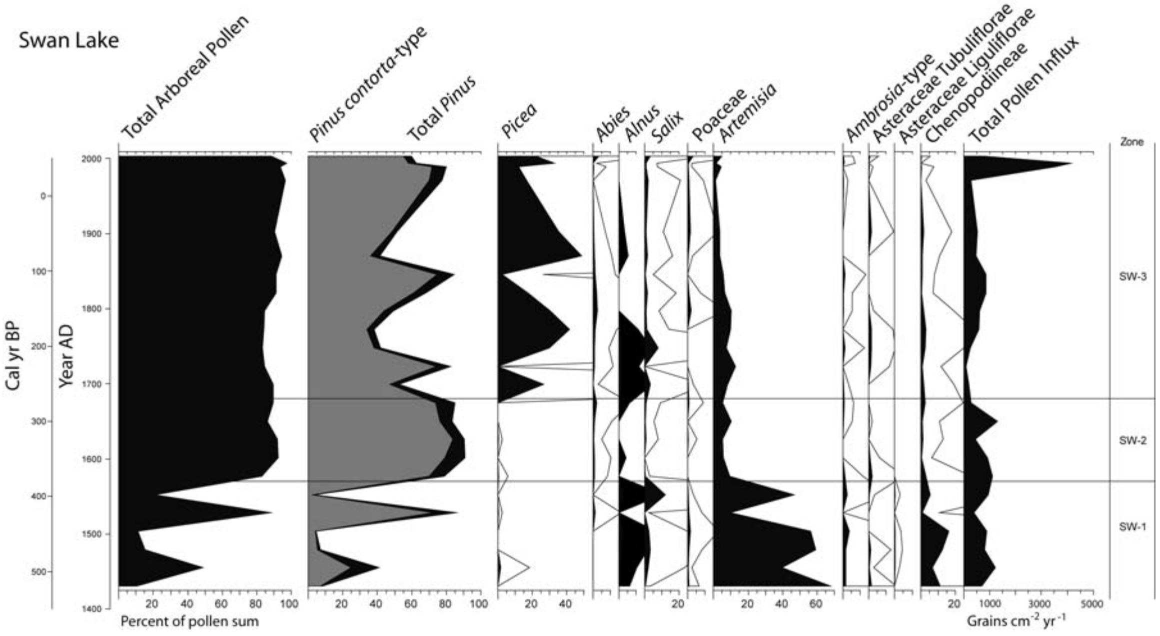

Figure 9: Pollen percentages and total pollen influx for Swan Lake. Outlined area is 10x exaggeration.

Zone SW-2 (41-53 cm depth; AD 1675-1575) featured the highest *Pinus* percentages (>80%) of the entire record. *Artemisia* values dropped below 11% and those of Chenopodiineae also dropped in this zone. Percentages of all other taxa remained low. Total PAR did not change appreciably in this zone. *Pinus contorta*-type percentages >60% are higher than modern values for *P. contorta* forests (Whitlock, 1993), suggesting that vegetation may have been denser around the site during zone SW-2. *Artemisia* percentages of <11% are consistent with modern values for lodgepole pine forests (Whitlock, 1993). The high percentages of *P. contorta* and low diversity of other pollen types suggest that the site was surrounded by a dense forest of lodgepole pine.

Zone SW-3 (0-41 cm depth; AD 2006-1675) was characterized by alternations of total *Pinus* and *Picea* percentages. Total *Pinus* percentages ranged between 40 and 80%, and *Picea* percentages ranged between 0 and 50%. *Abies* percentages were steady through this zone (average 1.3%). *Artemisia* percentages declined from 12 to 3% at the top of this zone. Pollen of other herb and shrub taxa (e.g. *Ambrosia*-type, Chenopodiineae) were poorly represented. The top sample showed a slight decrease in total *Pinus* (59 – 55%) and *Picea* (32 – 21%) and increases in *Abies* (to 3%), *Salix* (to 3%), and Poaceae (to 3%). Total PAR changed little in this zone, except for a peak near AD 1980 of 41,000 grains cm^{-2} $year^{-1}$.

Modern *Pinus contorta* forests exhibit similar percentages as registered in Zone SW-3 (Whitlock, 1993) but the high *Picea* percentages of up to 25% are noteworthy. This suggests that *Picea* was an important part of the forest since AD 1675. During this time, the watershed around Swan Lake was changing as the large Pilgrim Creek alluvial fan continued to aggrade (K. Pierce, written comm., 2006). Such changes in the Pilgrim Creek alluvial fan may have expanded riparian habitat and allowed *Picea* to grow. Other riparian taxa, such as *Salix* and *Alnus*, also increased at the beginning of Zone SW-3, suggesting a local increase in wetlands. Insect infestations or local fires may have caused the alternations of total *Pinus* and *Picea*. *Picea* is a fire-sensitive genus, while *Pinus contorta* is fire tolerant (Agee, 1993). The drop in *Picea* at ca. AD 1730 and at AD 1850 could be a response to local fires, and the latter drop is coincident with a charcoal peak in the Swan Lake record.

DISCUSSION

Local Vegetation and Fire History

To understand the last 2000 years of vegetation and fire history of Jackson Hole, the local vegetation and fire histories from each site must be compared. The vegetation history of Hedrick Pond is based on pollen data of the last 2100 years. The high values of *Pinus* and *Artemisia* pollen show little variation during this period, suggesting that the position of the forest/steppe ecotone has not changed substantially in during that period. The presence of Asteraceae Liguliflorae pollen and high percentages of Poaceae pollen before AD 850 suggests that the area around Hedrick Pond may have been drier than at present. *Salix* was consistently present in the Hedrick Pond record after ca. AD 1150 due to conditions gradually becoming wetter. The increase in *Pinus* pollen at ca. AD 1800 provides evidence of even wetter conditions in recent centuries. The resurgence of *Artemisia* and the decline in total *Pinus* after AD 1900 suggest an expansion of steppe communities in the region. This change in vegetation may have been caused by a change in fire regime or result from forest clearance by early settlers in the area.

Sediments from Pothole Lake record an extreme dry period before ca. AD 950. The presence of dry silty sediment at the base of the core implies that the site was only intermittently wet prior to AD 950. Abundant *Artemisia* pollen after AD 950 suggests dry conditions. An increase in total *Pinus* percentages after AD 1900, unlike the Hedrick Pond record, may be attributed to increased density of forest stands that grow in pockets near the lake and at the forest/steppe ecotone. The appearance of *Abies* pollen after AD

1900 implies the expansion of *A. lasiocarpa* in these low-elevation forests. Historic and modern photographic comparisons, for example, indicate that low-elevation forest in many parts of the GYE have become more dense in the last 150 years, as a result of fire elimination (Meagher and Houston, 1998).

The Swan Lake record began in AD 1430 and the earliest vegetation there was sagebrush steppe, as evidenced by the high percentages of *Artemisia*. The silty sediments during the sagebrush steppe period suggest fluvial input during this period from Pilgrim Creek, and the site may have dried intermittently. At 47 cm depth (ca. AD 1620), silty sediments were replaced by clay, suggesting that Swan Lake was dammed at its southern end by the buildup of the large Pilgrim Creek alluvial fan. As the fan built up, the lake became isolated and water depth increased (K. Pierce, written comm., 2006). The pollen data suggest a shift from *Artemisia* to *Pinus contorta* forest at ca. AD 1570 and expansion of *Picea* at ca. AD 1670. These changes indicate locally cooler and/or wetter conditions after ca. AD 1570, but whether they are related to regional cooling or simply changes in local hydrology that allowed spruce to grow in riparian forests cannot be determined.

At Hedrick Pond and Pothole Lake, which span the last 1000 years, fire episodes were registered at AD 1980-2000, 1785-1805, 1540-1550, 1385-1445, and 1055-1105 (Figure 10). Because Hedrick Pond is separated from Pothole Lake by the Snake River, a significant barrier to fire, these periods probably indicate times of many fires in Jackson Hole, rather than one large fire that burned both sites.

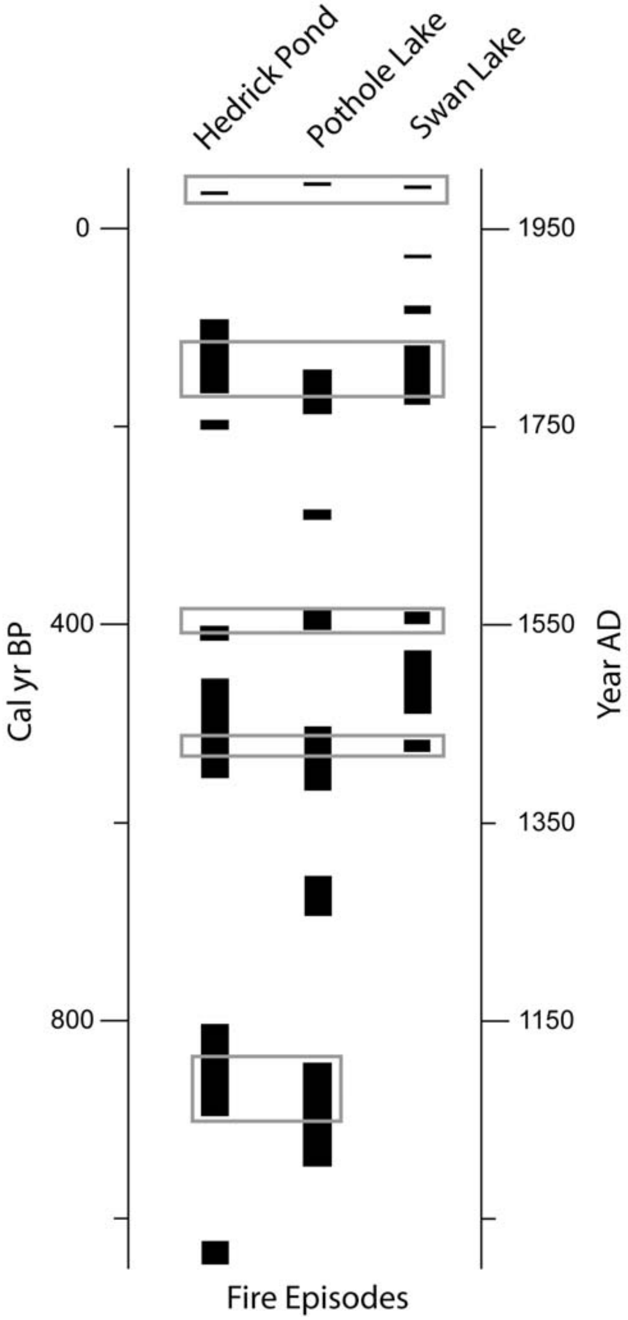

Figure 10: Comparison of fire episodes from each site for the last 1000 years. Gray boxes highlight times when fire episodes overlap.

For all three sites that span the last 550 years, fire episodes overlapped in AD 1980-2000, 1780-1820, 1540-1550, and 1420-1430 (Figure 10). A few of these fire episodes match known fire events registered in tree-ring and historical records. For example, fires were widespread within Jackson Hole in the 1980s (Grand Teton National Park Fire Management Office, 2006), and registered as charcoal peaks at all three sites dating from ca. AD 1980 to the mid 1990s. Tree-ring records indicate several fire years in Jackson Hole in the early to mid 19th century (Loope, 1974). For example, dendrochronologic studies indicate that fires occurred in the 1880s, 1870s, 1850s, and late 1700s in the Potholes area and south of Jackson Lake. The charcoal data from Hedrick Pond and Pothole Lake register the late 1700s and early 1800s fires, but not the 1880s events (Figures 4, 5, 10). Perhaps the fires in the 18th and early 19th centuries were more severe and produced more charcoal than the 1880s event, or perhaps earlier fires were located closer to Hedrick Pond and Pothole Lake. Tree-ring records also register fire events in the Colter Bay area in the 1850s and around AD 1910 (Loope, 1974), and these likely account for the charcoal peaks at Swan Lake dated at ca. AD 1860 and 1910 (Figures 6, 10). Other fire episodes at Swan Lake dating to the 1770s to the 1830s are not evident in the tree-ring data.

The occurrence of fires and particularly of periods of high fire activity registered at more than one site raise questions about the source of ignition (Baker and Ehle, 2001). In other regions of the western U.S., prehistoric people and their activities have been used to explain pre-European fire patterns (Barrett and Arno, 1982; Keely, 2002). Native Americans inhabited Jackson Hole for at least the last 10,000 years, with the oldest records dated by projectile point type (Connor, 1998; K. Pierce, written comm., 2006). Archaeological sites consisting of roasting pits and concentrations of material such as knives and projectile points are found throughout the valley. The age of artifact assemblages suggests that seasonal occupation changed over time, and specifically within the last 2000 cal years. Season of occupancy is inferred from the type of roasting pits at a site, and other utensils and food remnants found around the roasting pits (Connor, 1998). The northern portion of the valley was heavily occupied in the late summer and fall from AD 0 to 1150, and the number of roasting pits found in the park reached a peak during this period. Between AD 1150 and 1750, more sites were found in southern Jackson Hole than before, and they are thought to have been occupied in the spring and summer because fewer roasting pits are found there and food processing and storage were not important activities in the spring and early summer (Connor, 1998). Native occupation of the valley ended with European-American settlement in the mid-nineteenth century.

The fire records from the three sites in this study show no change in the spatial pattern of fire occurrence around AD 1100 when use of the southern end of the valley was increasing. Specifically, the Hedrick Pond record does not show an increase in fire activity at ca. AD 1100 that would coincide with the change in Native American occupancy. Native Americans could have been responsible for any of the fire episodes registered at the three sites (Figure 10); however, the charcoal records offer no clear evidence that changes in Native American's use of the valley were accompanied by changes in burning activities on the part of Native peoples.

Trappers and fur-traders entered Jackson Hole in the early nineteenth century (Daugherty, 1999), and may have been the first Europeans to alter the fire regime. John Colter, a member of the Lewis and Clark Expedition, was allegedly first white man to travel through Jackson Hole in 1807. A group representing John Jacob Astor's fur trading company passed through the valley in 1811, and the Tetons became a major landmark for trappers in the Greater Yellowstone area for the next 30 years. In 1860, a military expedition under the leadership of Captain W.F. Raynolds entered Jackson Hole as the first of three military surveys to pass through the area. The most important of these surveys was the 1872 survey headed by F.V. Hayden. The 1872 Hayden Survey produced a generally accurate map of the Teton Range and surrounding area (Daugherty, 1999). The photographer William Henry Jackson took the first photographs of the Grand Teton and the Teton Range during the 1872 survey. The effects of fire were noted in journals from the surveys that passed through the area, most notably in 1872 and 1877.

Miners explored the valley in the 1860s and 1870s. Seeking gold, prospectors panned nearly every stream in the valley, and elaborate placer mines were set up on Pilgrim Creek (Daugherty, 1999). Although the timing of local mining activities is not precisely coincident with the charcoal evidence of fires in the early 1800s (possibly due to dating error), fires started by miners may account for the charcoal peak in the Swan Lake record at ca. AD 1850 (the peak spans two decades from 1850 to 1870). No miners ever found a source of gold, and mining had little impact on the history of Jackson Hole (Daugherty, 1999).

The first homesteaders in Jackson Hole arrived in AD 1884, and were perhaps the first to established year-round occupants of the valley. According to the 1900 census (Census of the United States, 1900, Jackson Precinct; Daugherty, 1999), 638 people lived in the valley including the towns of Jackson, Moran and Kelly; the numbers of settlers steadily increased after AD 1900 (Daugherty, 1999). Farmers and ranchers settled mainly in the southern valley near Jackson. Popular crops were oats, barley, wheat and alfalfa, planted on land that the farmers had burned and cleared from acres of sagebrush (Daugherty, 1999). Fires started by farmers specifically for land clearance are not evident in any charcoal records used in this study. However, the decrease in *Pinus* pollen and increase in *Artemisia* pollen after AD 1900 at HedrickPond are consistent with forest clearance and wood gathering activities around the Triangle X Ranch, 2 km northeast of the lake.

Although Native Americans occupied Jackson Hole throughout the last 2000 years their activities are not evident in the pollen and charcoal records used in this study. Native Americans may have started fires in the past, but their activities cannot be resolved from the records. Euro-Americans may have also started fires in Jackson Hole; their activities more closely coincide with large fire episodes in the charcoal records from Hedrick Pond, Pothole Lake and Swan Lake. Forest clearance by Euro-Americans for ranching and farming activities was recorded in the Hedrick Pond record.

Vegetation, Fire and Climate Relationships

To examine the relation between changes in vegetation and fire regimes in Jackson Hole and the conditions that may have promoted fire, I compared the percentages of arboreal taxa (AP) to background charcoal accumulation (BCHAR; Figure 11) at Hedrick Pond, Pothole Lake and Swan Lake. AP is a measure of the sum of tree pollen, and high values imply a dominance of forest cover (Whitlock and Bartlein, 1997).

BCHAR describes the general trends in the charcoal data, and is considered a proxy for levels of biomass burning. High BCHAR thus implies a period when fires produced large amounts of charcoal, as a result of the available fuels and the size, proximity, or intensity of the fires (Long et al., 1998; Marlon et al., 2006). I use the term *high fire activity* to describe periods with high BCHAR, indicating large amounts of available fuel biomass, or fires that produced high amounts of charcoal. A period of low fire activity was a time with low BCHAR, indicating low amounts of available fuel biomass, or fires that produced low amounts of charcoal. Fire episodes are registered throughout the last 2000 years, but the levels of charcoal (BCHAR) suggest that they were variable in size or intensity (Figure 11).

Data from the three sites in Jackson Hole was compared with independent climate reconstructions and information on past human activity from the region (Figure 12). The climate reconstruction is divided into two widely recognized climate events. The Medieval Climate Anomaly (MCA) occurred between ca. AD 800 and 1400. The MCA is defined as the period of higher-than-normal summer temperatures in several Northern Hemisphere regions including Scandinavia, China, California and the Rocky Mountains (Hughes and Diaz, 1994; Mann and Jones, 2003). In the western United States, the MCA was a period of drought but not necessarily higher-than-normal summer temperatures (Cook et al., 2004). The Little Ice Age (LIA) refers to a period of renewed glacial activity that occurred over several centuries within the last 1000 years in Europe (Free and Robock, 1999). It is not time synchronous globally and some have recommended that the term be dropped (e.g. Landsberg, 1980). In the northern Rocky

Mountains, LIA maxima were generally reached between AD 1700 and 1900 (Luckman, 1994). Global temperatures between AD 1500 and 1900 were cooler than in the past century, with the coldest periods in the Northern Hemisphere occurring from AD 1570 to 1730 and ca. AD 1800 to 1900 (Free and Robock, 1999; Mann et al., 1998).

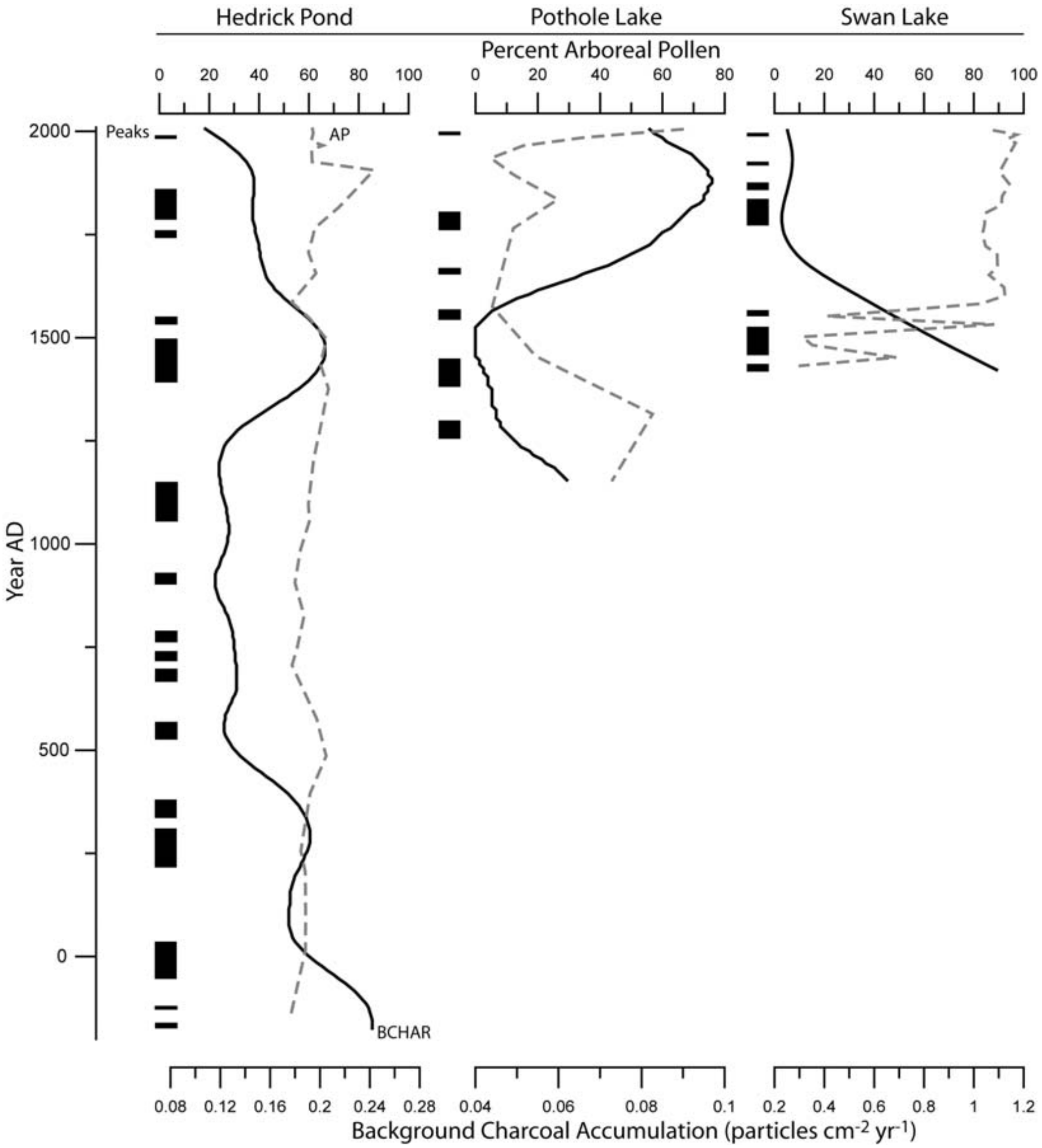

Figure 11: A comparison of peaks in charcoal accumulation (CHAR), total arboreal pollen (dashed gray lines) and background CHAR (BCHAR) for each site. Note that the total arboreal pollen scale for Hedrick Pond extends from 50 to 90%, and only the last 750 years is shown from Pothole Lake.

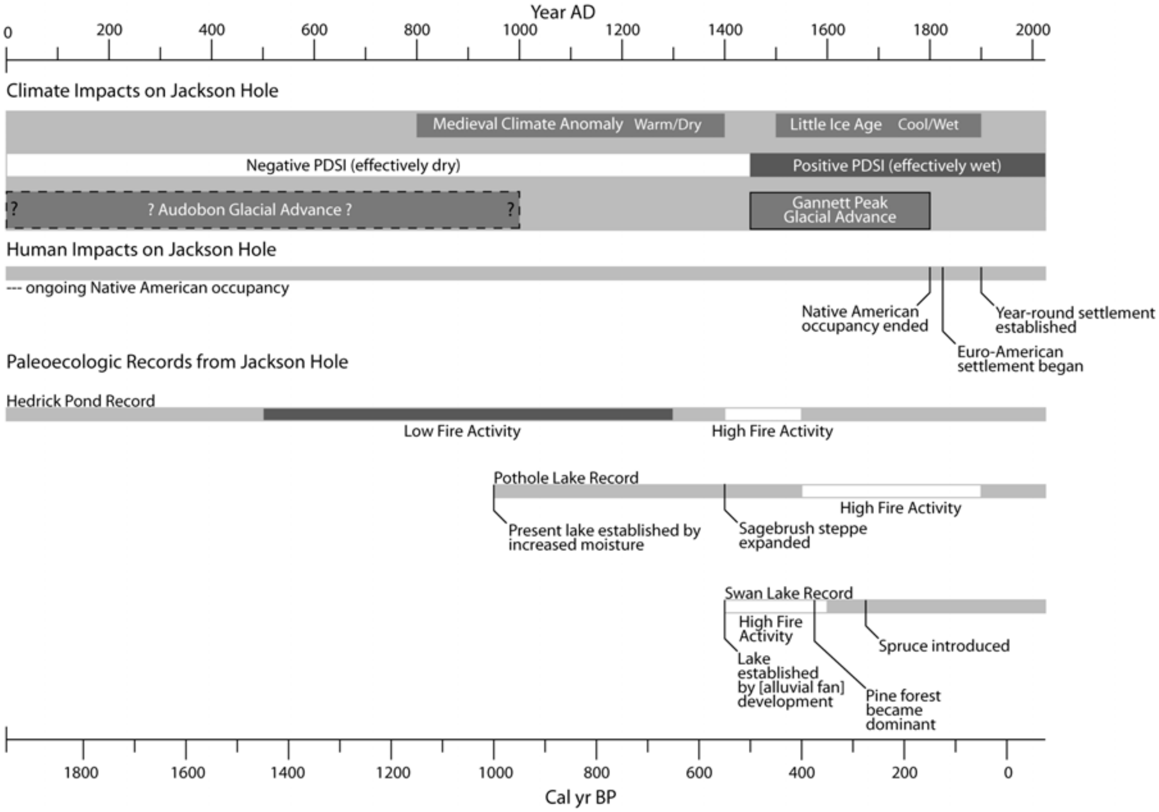

Figure 12: Timeline of climate events, human impacts, and important inferences from the paleoecologic records in Jackson Hole. Low fire activity indicates a time when available fuel biomass was low, or fires produced low amounts of charcoal. High fire activity indicates a time when available fuel biomass was high, or fires produced high amounts of charcoal.

A higher resolution paleoclimate dataset is the reconstructed Palmer Drought Severity Index (PDSI), which is a measure of dryness based on precipitation and temperature (NOAA, 2006). PDSI data used for comparison in this study are based on a network of long tree-ring chronologies throughout the United States (Cook et al., 2004). The PDSI data indicate an effectively dry period for the Greater Yellowstone Ecosystem (GYE) from ca. AD 0 to 1450, and effectively wet conditions are indicated from ca. AD 1450 to present (gridpoint 100; Cook et al., 2004).

Glacial advances are associated with periods of cooler summers (Pederson et al., 2004), and the data from the Teton Range provide paleoclimate information. The Gannett Peak cirque glacial advance in the Teton Range occurred between ca. AD 1450 and 1800 (Mahaney and Spence, 1990). The Audobon advance occurred some time before ca. AD 1000, but the timing is questionable because these cirque glacial advances were dated using several relative dating methods (Mahaney and Spence, 1990).

As discussed previously, major human impacts on Jackson Hole included the presence of Native Americans since ca. 9000 cal yr BP (Connor, 1998), whose use of the valley included more southern sites after AD 1300. Native American occupancy of the valley ended at ca. AD 1800 (Daugherty, 1999), and was followed by the appearance of Euro-Americans in the early 19th century. Euro-Americans established year-round settlements in Jackson Hole at ca. AD 1890.

Fire episodes are registered throughout the last 2000 years, but the levels of charcoal (BCHAR) suggest that they were variable in size or intensity. At Hedrick Pond fire activity was low from ca. AD 500 to 1350 (Figure 11), coincident with a dry period in the region as indicated by the PDSI data (Figure 12). A period of high fire activity occurred at Hedrick Pond from ca. AD 1400 to 1550, and was associated with a shift from negative (dry) to positive (wet) PDSI values at ca. AD 1450. High fire activity at Hedrick Pond may have been caused by increased fuel buildup in response to wetter conditions, creating more biomass available for burning, however the percent AP at Hedrick Pond shows little change to indicate major shifts in vegetation at the forest-steppe ecotone.

The Pothole Lake record began at ca. AD 950 in response to locally increasing available moisture. Prior to ca. AD 1400, BCHAR was relatively low indicating low fire activity. A continuing increase in available moisture caused the sagebrush steppe vegetation around Pothole Lake to expand at ca. AD 1400 as evidenced by the decrease in AP. A period of high fire activity (high BCHAR) occurred from ca. AD 1550 to 1900, most likely caused by increased availability of sagebrush as a fuel. The LIA is associated with high PDSI values after AD 1450, and wet conditions would have caused sagebrush to increase in abundance, thereby increasing charcoal production when fires occurred (e.g. Mensing et al., 2006). Sagebrush desiccates quickly and is generally more available for burning than forest fuels (USDA Forest Service, 2006). During a wet period such as the LIA, sagebrush would grow rapidly and be available for burning, even during moderately dry years.

Swan Lake was established at the beginning of the wet period in the region (ca. AD 1400), when the alluvial fan from Pilgrim Creek blocked its outlet. The period from ca. AD 1400 to 1600 was characterized by high fire activity and open vegetation, as inferred from high values of BCHAR and low AP. The high fire activity at this time coincides with the beginning of wet conditions also seen at Pothole Lake. The pollen data suggest that pine forest became dominant around Swan Lake after ca. 1570 and spruce became an important constituent of the forest around Swan Lake at ca. AD 1670. The pollen of these two conifers accounts for the rise in AP at AD 1570. The expansion of forests in the region probably explains the decrease in fire activity at Swan Lake at this time.

The vegetation and fire histories at the three sites in this study show a markedly different response to the same regional climate variations. However, when interpreted in the context of the dominant vegetation, each site shows evidence of the same basic pattern of increasingly wet conditions towards present-day. Evidence for human activity, both Native American and Euro-American, is scant but does not disagree with historical records.

CONCLUSIONS

The pollen and charcoal records from Hedrick Pond, Pothole Lake and Swan Lake provide information on past changes in vegetation and fire regimes during the last 2000 years. These data were compared with paleoclimate proxy from the region, climate indices, archaeological, and historical data to examine the relative importance of climate versus anthropogenic activities in shaping the lower forest and steppe communities of Jackson Hole. The charcoal data suggest a period of low fire activity prior to AD 1000 that is consistent with drier-than-present conditions at that time. Each site responded to local and regional conditions, but all three records show increasingly wet conditions towards present day. For example, Pothole Lake showed increased water depth at ca. AD 1000, and Swan Lake experienced an increase in spruce pollen at ca. AD 1670. Periods of dry conditions in the past 1000 years supported many fires throughout Jackson Hole, with fires recorded at more than one lake at the same time. Dry climatic conditions within the past 2000 years caused low fire activity at Hedrick Pond due to fuel limitations. Increasingly wet conditions caused high fire activity at all three sites in the valley, because of increased available moisture for plant growth.

Native Americans may have been an ignition source in the past; however, the spatial pattern of fire, as recorded at the three sites, does not match inferred shifts in human occupancy in the valley, and particularly the shift to southern valley sites after AD 1300. Similarly, there is no conclusive evidence of Euro-American burning activities in any of the records in Jackson Hole, although it is likely that mining and homesteading activities could have altered the fire regime. However, Euro-American settlement coincides with increased fire activity in the valley, and mining activities occurred near Swan Lake around the time of a major fire peak in that record. Euro-Americans apparently did have a significant influence on vegetation in Jackson Hole. Forest clearance by settlers is evidenced in the Hedrick Pond record as a decline in pine pollen after ca. AD 1900.

This study highlights the importance of low-elevation pollen and charcoal studies for understanding the responses of low-elevation ecosystems to climate and human impacts. This study shows that charcoal records from closely spaced sites can be compared and give evidence for widespread fires in the past, although evidence for single large fires will require high resolution records. In a local context, Euro-Americans had the most influence of any humans in Jackson Hole in the past 2000 years, especially due to their logging efforts and forest clearance. More records are needed to further study the impact of climate and human activity in Jackson Hole. Sites should to be chosen from other ecological settings such as alpine environments and montane forests. To aid in the development of climatic records, more tree-ring and tree-ring fire-scar records need to be collected from Grand Teton National Park. Longer records should be studied to fit the data from the last 2000 years in to a broader temporal context.

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APPENDICES

APPENDIX A:

KEY TO POLLEN TAXA

ABE – *Abies*
ACE – *Acer*
ALN – *Alnus*
AMB – *Ambrosia*-type
AME – *Amelanchier*
ART – *Artemisia*
BET – *Betula*
BOT – *Botrychium*-type
BRA – *Brasenia*
CARY – Caryophyllaceae
CHEN – Chenopodiineae
CYP – Cyperaceae
DEG - degraded
DRY – *Dryopteris*
ELE – Eleagnaceae
EPH – *Ephedra*
EQU – *Equisetum*
GIL – *Gilia*-type
ISO – *Isoetes*
IVA – *Iva xanthifolia*
JUN – *Juniperus*
LIG – Liguliflorae
LYC – *Lycopodium* (spike)
MAL – Malvaceae
MYR – *Myriophyllum*
NUP – *Nuphar*
P ALB – *Pinus albicaulis*-type
P AMPH – *Polygonum amphibium*-type
P CONT – *Pinus contorta*-type
P UNDIF – *Pinus* undifferentiated
PIC – *Picea*
PLAN – *Plantago*
POA – Poaceae
POLY – other Polygonaceae
POP – *Populus tremuloides*-type
POT – *Potamogeton*
PSU – *Pseudotsuga*
PTE – *Pteridium*-type
QUE – *Quercus*
RAN – other Ranunculaceae
ROS – Rosaceae
RUM – *Rumex*
SAL – *Salix*
SALS – *Salsola*-type
SAR – *Sarcobatus*
SPA – *Sparganium*-type

SPH – *Sphagnum*
SPI – *Spirea*
THAL – *Thalictrum*
TUB – other Tubuliflorae
UMB – other Umbelliferae
UNK – unknown

APPENDIX B:

RAW POLLEN COUNTS

Hedrick Pond Raw Pollen Counts															
Depth (cm)	P CONT	P ALB	P UNDIF	PIC	ABE	PSU	JUN	ALN	BET	SAL	POP	QUE	ACE	AME	EPH
0	112	2	46	0	4	2	0	0	0	2	0	1	0	1	0
4	119	2	50	2	4	2	0	0	0	1	0	1	0	0	0
8	126	2	52	3	4	2	0	0	0	1	0	2	0	0	0
10	125	11	3	6	3	2	0	2	1	1	0	1	0	0	0
12	133	2	55	4	4	1	0	0	0	1	0	3	0	0	0
16	135	2	56	6	5	1	0	0	0	1	0	3	0	0	0
20	228	18	103	0	2	0	0	2	0	1	1	0	0	0	0
30	110	20	12	2	2	1	0	1	1	2	0	0	1	0	0
35	75	7	44	3	2	0	1	0	0	1	0	0	0	0	0
40	115	6	10	5	2	1	1	1	0	1	0	1	0	0	0
44	120	14	30	8	5	3	2	2	0	1	0	1	0	0	2
50	82	15	31	5	3	2	1	1	1	1	0	0	2	0	0
53	99	17	39	5	2	3	3	2	3	2	0	2	0	1	0
56	110	20	42	9	3	1	3	3	3	4	0	2	0	3	0
60	107	19	38	10	2	2	2	1	1	1	0	1	0	1	0
64	122	26	33	6	3	2	3	2	2	3	0	1	0	0	0
66	129	30	34	5	3	1	2	1	0	2	0	1	0	0	0
70	117	31	32	7	2	2	1	0	0	2	0	0	0	0	0
74	119	23	31	6	3	2	2	0	0	1	0	0	0	0	0
80	115	17	39	2	3	1	0	0	0	0	0	0	0	0	0
82	114	21	40	8	1	1	0	0	0	0	0	0	0	0	0
86	122	20	35	5	2	0	1	2	0	1	1	3	0	0	0
90	112	18	33	2	2	0	3	1	0	4	2	3	0	0	0
94	108	12	45	2	2	0	3	1	0	5	4	1	0	0	0
98	90	11	50	6	3	0	2	0	1	1	0	0	0	0	1
100	92	11	45	11	2	0	3	2	4	3	0	0	0	0	2
106	104	23	40	3	5	2	1	0	0	0	0	0	2	0	1
110	108	45	30	0	3	1	2	0	0	0	0	0	1	0	0
114	110	20	42	1	3	3	0	2	2	1	0	0	0	0	0
120	114	14	35	5	3	4	0	2	1	2	0	0	0	0	0
122	116	19	42	3	3	2	0	2	2	3	0	0	0	0	0
126	107	21	41	5	6	0	2	1	0	2	0	1	0	0	0
130	109	14	38	4	4	0	2	0	0	0	0	2	0	0	0
136	102	22	43	2	3	0	3	3	2	3	0	1	0	0	0

Hedrick Pond Raw Pollen Counts										
Depth (cm)	SAR	POA	CYP	ART	AMB	TUB	LIG	CHEN	THAL	UMB
0	0	3	0	87	3	2	1	9	0	0
4	0	6	0	91	4	3	0	8	0	0
8	0	9	0	94	5	5	0	10	0	0
10	1	10	0	58	4	1	0	7	0	0
12	0	10	0	97	5	6	0	11	0	0
16	0	13	0	98	5	5	0	11	0	0
20	4	0	0	38	3	1	0	11	0	0
30	2	14	5	33	2	4	0	4	0	0
35	2	16	0	51	1	3	0	7	0	0
40	2	17	7	65	2	2	0	8	0	0
44	3	17	5	69	8	3	0	8	0	0
50	6	10	5	90	5	5	0	10	0	1
53	5	11	7	78	5	6	0	8	0	2
56	2	8	3	71	2	5	0	6	0	1
60	2	6	0	76	2	5	0	9	0	0
64	2	10	9	72	3	3	0	6	0	0
66	3	15	8	68	3	6	0	8	0	1
70	1	16	8	79	2	3	0	6	0	0
74	3	18	5	75	5	6	0	8	0	0
80	3	14	2	87	2	4	0	8	0	1
82	2	18	3	78	7	5	2	9	0	1
86	4	29	7	83	5	9	4	12	0	0
90	2	36	9	88	3	6	2	14	0	0
94	3	24	9	75	3	6	5	16	0	0
98	5	18	12	80	6	5	2	13	0	0
100	5	23	6	93	6	3	0	16	2	0
106	2	20	5	66	2	3	2	9	0	0
110	0	18	4	61	3	3	2	7	0	0
114	5	24	3	74	6	2	0	8	1	0
120	4	29	22	84	3	4	0	12	1	0
122	5	27	11	80	8	2	0	11	3	0
126	3	29	30	75	6	3	0	10	4	1
130	1	30	60	71	4	4	0	10	1	1
136	5	31	36	87	9	7	5	15	3	1

Hedrick Pond Raw Pollen Counts									
Depth (cm)	CARY	RUM	LYC	SPA	POT	MYR	NUP	Sum	Terr Sum
0	0	0	338	0	1	0	8	508	161
4	0	0	282	0	1	0	6	469	180
8	0	0	282	0	1	0	5	491	203
10	0	0	155	0	0	1	4	280	120
12	0	0	267	0	2	0	8	498	221
16	0	0	263	0	2	0	9	510	236
20	0	0	131	0	0	0	3	340	206
30	0	0	151	0	0	1	1	299	141
35	0	0	165	0	0	0	1	367	201
40	0	0	160	0	0	1	0	366	198
44	0	0	151	0	0	2	6	414	250
50	0	0	148	0	0	1	0	428	274
53	0	0	150	0	0	2	0	442	283
56	0	0	133	0	0	2	0	418	280
60	0	0	145	0	0	0	0	424	279
64	0	0	145	0	0	0	0	433	279
66	0	0	139	0	0	0	0	432	285
70	0	0	144	0	0	0	0	445	293
74	0	0	143	0	0	0	0	456	308
80	0	0	136	0	0	0	0	462	324
82	0	0	144	0	0	2	0	485	336
86	0	1	150	0	0	2	0	528	369
90	0	0	145	0	0	2	0	537	381
94	0	0	146	0	0	3	0	541	383
98	3	0	148	0	0	0	0	552	392
100	2	0	144	0	0	0	0	572	422
106	0	0	144	1	0	0	0	520	370
110	0	0	139	1	0	0	0	495	351
114	0	0	145	0	5	1	0	556	402
120	0	0	152	0	15	2	0	620	429
122	0	0	141	0	6	3	0	598	437
126	0	0	149	0	9	5	0	634	441
130	0	0	146	0	7	4	0	649	432
136	0	0	147	0	8	2	0	688	495

Pothole Lake Raw Pollen Counts																						
Depth (cm)	P CONT	P ALB	P UNDIF	PIC	ABE	PSU	JUN	ALN	BET	SAL	POP	QUE	AME	ELE	EPH	SAR	POA	ART	AMB	TUB	LIG	CHEN
0	139	0	21	0	1	0	0	4	1	0	0	0	0	2	0	0	2	45	1	3	12	5
4	53	0	9	0	3	0	0	2	0	0	0	0	0	0	1	0	5	60	4	10	13	12
8	19	0	4	0	1	0	0	0	0	0	0	0	0	0	1	0	2	99	4	3	13	9
12	0	0	0	0	0	0	0	1	2	0	3	0	0	0	0	0	3	55	4	10	15	16
16	16	0	3	0	0	0	0	4	1	0	0	0	0	0	0	0	0	111	4	13	14	13
20	1	0	0	0	0	0	0	4	6	6	6	0	1	0	0	1	11	26	5	3	5	6
24	8	0	1	0	0	0	1	0	0	0	2	0	0	0	0	0	3	57	3	6	7	8
28	5	0	0	1	0	0	0	0	1	0	3	0	0	0	0	0	3	68	4	8	6	3
32	5	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	4	126	5	8	9	4
36	12	0	3	0	0	0	0	5	0	0	4	0	0	0	1	0	4	67	7	4	7	4
40	0	0	0	0	0	0	1	0	13	0	15	0	0	0	0	0	10	8	1	0	0	3
44	57	0	11	1	0	0	0	0	1	1	2	0	0	0	0	2	3	73	1	5	4	4
48	246	1	53	0	13	0	12	0	0	0	2	1	0	0	0	0	4	22	0	1	0	4
50	68	0	17	1	1	0	0	1	0	1	0	0	0	0	1	0	2	48	4	0	0	2
54	202	0	30	0	1	0	0	0	0	0	0	0	0	0	2	0	9	34	0	2	2	1
58	154	0	38	0	2	1	2	0	0	3	2	1	1	0	0	0	5	21	1	2	3	3
62	70	0	15	0	2	0	2	0	0	0	0	0	0	0	2	0	4	5	1	0	2	1
66	236	0	43	0	3	0	0	0	0	0	1	0	0	0	2	0	9	24	1	0	0	2

Pothole Lake Raw Pollen Counts																
Depth (cm)	SALS	RAN	CARY	POLY	GIL	PTE	DRY	LYC	EQU	POT	NUP	BRA	ISO	DEG	Sum	Terr Sum
0	0	2	3	0	0	6	3	187	0	0	0	1	1	0	439	250
4	0	0	19	0	0	1	1	163	0	1	0	0	0	0	361	197
8	0	0	3	0	0	0	0	99	0	0	0	0	0	0	265	166
12	0	0	12	0	0	0	0	118	0	0	0	0	0	0	251	133
16	0	1	13	0	0	4	0	233	0	0	0	0	0	0	446	213
20	0	0	3	0	1	2	0	136	0	0	1	0	0	2	246	107
24	0	0	3	0	0	0	0	132	0	0	0	0	0	0	255	123
28	0	0	3	2	0	1	0	195	0	0	0	0	0	0	331	136
32	0	0	1	0	0	1	0	182	0	0	0	0	0	0	381	199
36	0	0	0	0	0	5	1	185	0	0	0	0	0	0	345	160
40	0	0	0	0	0	0	0	123	0	0	0	0	0	0	214	91
44	0	0	1	0	0	0	0	164	0	0	0	0	0	0	374	210
48	2	0	0	0	0	1	0	82	0	0	0	0	0	0	492	410
50	0	0	0	0	0	1	0	359	0	0	0	0	0	0	556	197
54	0	0	0	0	0	0	0	363	0	0	0	0	0	0	700	337
58	0	0	0	0	0	1	0	263	0	0	0	2	0	2	565	298
62	0	0	0	0	0	2	0	276	1	0	0	0	0	2	447	168
66	0	0	0	0	0	0	0	269	0	0	0	0	0	0	656	387

Swan Lake Raw Pollen Counts

Depth (cm)	P CONT	P ALB	P UNDIF	PIC	ABE	PSU	JUN	ALN	BET	SAL	POP	QUE	ROS	SPI	AME	EPH	SAR	POA
0	98	0	8	39	6	0	0	0	0	6	0	0	0	0	1	0	1	6
3	248	2	17	140	1	0	0	0	0	3	1	2	0	0	0	0	1	1
6	283	2	31	47	3	1	0	0	0	3	0	0	0	0	0	0	0	1
9	237	2	23	56	0	2	0	0	0	7	0	0	0	0	0	0	0	3
13	135	2	7	99	2	3	0	1	0	3	0	0	0	0	0	0	1	5
17	133	1	18	179	4	2	0	2	0	6	0	1	0	0	0	0	1	1
20	284	0	38	10	5	0	0	0	0	2	5	1	1	2	1	0	1	0
23	336	0	40	97	13	1	0	0	1	10	5	0	0	0	0	0	0	4
26	160	3	16	111	10	1	0	0	0	3	2	0	2	0	0	1	0	8
29	121	1	14	148	5	0	0	4	0	5	1	0	0	0	0	0	0	0
32	122	0	13	96	3	0	0	6	2	26	0	0	0	0	1	0	2	0
35	63	0	7	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
38	146	3	14	83	1	0	1	6	2	11	3	7	0	0	0	0	0	1
41	239	2	34	0	7	0	1	2	2	3	0	0	0	0	0	0	1	3
44	419	2	36	0	6	0	3	0	0	3	3	0	0	0	1	0	0	0
47	319	3	22	1	2	0	0	0	0	3	1	0	0	0	1	1	0	2
50	380	5	49	0	5	1	0	2	0	0	1	0	0	0	0	1	1	0
53	243	1	30	2	3	0	2	0	1	1	4	0	0	0	0	0	1	0
56	8	0	3	0	0	0	7	8	1	38	0	0	0	0	0	0	2	1
59	269	1	49	1	6	0	0	0	0	1	0	0	0	0	0	0	0	3
62	11	0	2	0	0	0	0	6	2	7	2	0	1	0	0	0	0	5
65	13	0	4	0	0	0	0	4	2	8	5	0	0	0	0	0	2	2
68	96	0	62	7	0	0	0	4	2	9	7	1	0	0	0	0	1	1
71	22	0	4	0	0	0	1	2	0	1	1	1	0	0	0	0	5	2

Swan Lake Raw Pollen Counts

Depth (cm)	MAL	ART	AMB	IVA	TUB	LIG	CHEN	SALS	RAN	UMB	CARY	POLY	RUM	PLAN	PTE
0	0	9	1	0	1	0	1	0	0	0	0	0	0	1	0
3	0	7	3	0	0	0	0	0	0	0	0	0	0	0	0
6	0	18	0	0	1	0	3	0	0	0	0	0	0	0	2
9	0	4	1	0	0	0	1	0	0	0	0	0	0	0	2
13	0	10	0	0	4	0	5	0	0	0	0	0	0	0	2
17	0	13	0	0	0	0	4	0	0	0	0	0	0	0	0
20	0	22	5	0	0	0	3	1	0	0	0	0	0	0	0
23	0	36	3	0	0	0	4	0	0	1	0	1	0	0	0
26	0	37	2	0	1	0	7	0	0	0	0	0	0	0	0
29	1	35	0	0	5	0	11	1	0	0	0	0	2	0	1
32	0	23	4	0	5	0	8	4	0	2	0	2	0	0	2
35	0	11	0	0	1	0	1	0	0	0	0	0	0	0	0
38	0	25	1	0	0	0	6	0	0	0	0	0	0	0	0
41	0	17	2	0	0	0	8	0	0	0	0	0	0	0	3
44	0	56	3	0	1	0	6	1	0	0	0	0	7	1	0
47	0	20	0	0	0	0	5	0	0	0	0	0	0	0	1
50	0	27	0	0	3	0	3	0	0	0	0	0	0	1	0
53	1	33	4	0	7	0	10	0	0	0	0	0	0	0	2
56	0	145	8	2	1	1	17	0	0	0	0	5	0	0	56
59	0	37	0	0	0	0	4	0	0	0	0	0	0	0	0
62	0	155	10	0	0	1	45	3	1	0	0	12	7	2	1
65	0	141	4	0	3	1	30	9	0	0	0	0	9	1	0
68	0	153	6	0	1	1	26	1	0	0	0	0	6	1	0
71	0	210	5	0	5	0	35	6	0	0	1	0	0	0	5

Swan Lake Raw Pollen Counts													
Depth (cm)	DRY	LYC	BOT	UNK	EQU	SPH	POT	NUP	P AMPH	ISO	DEG	Sum	Terr Sum
0	0	242	0	0	0	0	0	2	0	0	0	422	178
3	0	135	0	0	0	0	0	4	0	1	0	572	432
6	0	142	0	0	1	0	0	3	0	0	1	554	407
9	0	175	0	0	1	0	0	3	0	0	0	535	356
13	0	182	0	0	0	0	0	5	0	0	0	492	305
17	2	261	0	0	1	0	0	5	0	1	1	670	401
20	0	150	0	0	0	0	0	0	0	0	0	571	421
23	0	221	0	0	0	0	0	2	0	0	0	821	598
26	0	200	0	0	0	0	0	4	0	0	0	620	416
29	0	211	0	0	2	0	0	3	0	0	4	633	413
32	0	439	1	0	1	0	0	2	0	1	3	832	385
35	0	365	0	0	1	0	0	0	0	0	0	521	155
38	0	521	0	0	0	0	0	1	0	0	7	915	386
41	0	388	0	0	0	0	0	0	0	1	2	797	406
44	0	145	0	0	0	0	0	0	0	0	0	781	636
47	0	293	0	0	0	0	0	2	0	0	0	770	475
50	0	181	0	0	0	0	0	8	0	0	1	769	579
53	2	106	0	0	0	0	0	0	0	0	1	560	453
56	8	112	0	0	0	0	0	0	1	0	7	543	423
59	0	318	0	0	0	1	0	2	0	0	0	810	489
62	3	107	0	0	1	0	0	1	0	0	16	525	400
65	0	102	0	0	0	1	3	0	0	0	9	483	368
68	0	107	0	0	3	0	0	1	0	0	5	637	521
71	4	150	0	5	7	0	2	0	0	0	3	619	452

APPENDIX C:

POLLEN PERCENTAGES

Hedrick Pond Pollen Percentages															
Depth (cm)	P CONT	P ALB	P UNDIF	PIC	ABE	PSU	JUN	ALN	BET	SAL	POP	QUE	ACE	AME	EPH
0	40.7273	0.727	16.7273	58	0	1.45	0.7	0	0	0	0.73	0	0.36	0	0.36
4	40.6143	0.683	17.0648	58	0.68	1.37	0.7	0	0	0	0.34	0	0.34	0	0
8	40	0.635	16.5079	57	0.95	1.27	0.6	0	0	0	0.32	0	0.63	0	0
10	52.9661	4.661	1.27119	59	2.54	1.27	0.8	0	0.8	0.4	0.42	0	0.42	0	0
12	40.0602	0.602	16.5663	57	1.2	1.2	0.3	0	0	0	0.3	0	0.9	0	0
16	39.5894	0.587	16.4223	57	1.76	1.47	0.3	0	0	0	0.29	0	0.88	0	0
20	55.3398	4.369	25	85	0	0.49	0	0	0.5	0	0.24	0.24	0	0	0
30	52.1327	9.479	5.6872	67	0.95	0.95	0.5	0	0.5	0.5	0.95	0	0	0.47	0
35	35.2113	3.286	20.6573	59	1.41	0.94	0	0.5	0	0	0.47	0	0	0	0
40	48.1172	2.51	4.1841	55	2.09	0.84	0.4	0.4	0.4	0	0.42	0	0.42	0	0
44	40.5405	4.73	10.1351	55	2.7	1.69	1	0.7	0.7	0	0.34	0	0.34	0	0
50	30.2583	5.535	11.4391	47	1.85	1.11	0.7	0.4	0.4	0.4	0.37	0	0	0.74	0
53	33.7884	5.802	13.3106	53	1.71	0.68	1	1	0.7	1	0.68	0	0.68	0	0.34
56	36.9128	6.711	14.094	58	3.02	1.01	0.3	1	1	1	1.34	0	0.67	0	1.01
60	37.5439	6.667	13.3333	58	3.51	0.7	0.7	0.7	0.4	0.4	0.35	0	0.35	0	0.35
64	40.8027	8.696	11.0368	61	2.01	1	0.7	1	0.7	0.7	1	0	0.33	0	0
66	41.3462	9.615	10.8974	62	1.6	0.96	0.3	0.6	0.3	0	0.64	0	0.32	0	0
70	38.8704	10.3	10.6312	60	2.33	0.66	0.7	0.3	0	0	0.66	0	0	0	0
74	39.404	7.616	10.2649	57	1.99	0.99	0.7	0.7	0	0	0.33	0	0	0	0
80	38.8514	5.743	13.1757	58	0.68	1.01	0.3	0	0	0	0	0	0	0	0
82	37.1336	6.84	13.0293	57	2.61	0.33	0.3	0	0	0	0	0	0	0	0
86	35.9882	5.9	10.3245	52	1.47	0.59	0	0.3	0.6	0	0.29	0.29	0.88	0	0
90	33.8369	5.438	9.96979	49	0.6	0.6	0	0.9	0.3	0	1.21	0.6	0.91	0	0
94	34.2857	3.81	14.2857	52	0.63	0.63	0	1	0.3	0	1.59	1.27	0.32	0	0
98	30.303	3.704	16.835	51	2.02	1.01	0	0.7	0	0.3	0.34	0	0	0	0
100	28.3077	3.385	13.8462	46	3.38	0.62	0	0.9	0.6	1.2	0.92	0	0	0	0
106	36.4912	8.07	14.0351	59	1.05	1.75	0.7	0.4	0	0	0	0	0	0.7	0
110	38.0282	15.85	10.5634	64	0	1.06	0.4	0.7	0	0	0	0	0	0.35	0
114	36.1842	6.579	13.8158	57	0.33	0.99	1	0	0.7	0.7	0.33	0	0	0	0
120	35.9621	4.416	11.041	51	1.58	0.95	1.3	0	0.6	0.3	0.63	0	0	0	0
122	35.3659	5.793	12.8049	54	0.91	0.91	0.6	0	0.6	0.6	0.91	0	0	0	0
126	33.7539	6.625	12.9338	53	1.58	1.89	0	0.6	0.3	0	0.63	0	0.32	0	0
130	36.9492	4.746	12.8814	55	1.36	1.36	0	0.7	0	0	0	0	0.68	0	0
136	29.3948	6.34	12.3919	48	0.58	0.86	0	0.9	0.9	0.6	0.86	0	0.29	0	0

Hedrick Pond Pollen Percentages										
Depth (cm)	SAR	POA	CYP	ART	AMB	TUB	LIG	CHEN	THAL	UMB
0	0	0	1.09	0	31.6	1.1	0.7	0.364	3.27	0
4	0	0	2.05	0	31.1	1.4	1	0	2.73	0
8	0	0	2.86	0	29.8	1.6	1.6	0	3.17	0
10	0	0.42	4.24	0	24.6	1.7	0.4	0	2.97	0
12	0	0	3.01	0	29.2	1.5	1.8	0	3.31	0
16	0	0	3.81	0	28.7	1.5	1.5	0	3.23	0
20	0	0.97	0	0	9.22	0.7	0.2	0	2.67	0
30	0	0.95	6.64	2.3	15.6	0.9	1.9	0	1.9	0
35	0	0.94	7.51	0	23.9	0.5	1.4	0	3.29	0
40	0	0.84	7.11	2.8	27.2	0.8	0.8	0	3.35	0
44	0.68	1.01	5.74	1.6	23.3	2.7	1	0	2.7	0
50	0	2.21	3.69	1.8	33.2	1.8	1.8	0	3.69	0
53	0	1.71	3.75	2.3	26.6	1.7	2	0	2.73	0
56	0	0.67	2.68	1	23.8	0.7	1.7	0	2.01	0
60	0	0.7	2.11	0	26.7	0.7	1.8	0	3.16	0
64	0	0.67	3.34	2.9	24.1	1	1	0	2.01	0
66	0	0.96	4.81	2.5	21.8	1	1.9	0	2.56	0
70	0	0.33	5.32	2.6	26.2	0.7	1	0	1.99	0
74	0	0.99	5.96	1.6	24.8	1.7	2	0	2.65	0
80	0	1.01	4.73	0.7	29.4	0.7	1.4	0	2.7	0
82	0	0.65	5.86	1	25.4	2.3	1.6	0.651	2.93	0
86	0	1.18	8.55	2	24.5	1.5	2.7	1.18	3.54	0
90	0	0.6	10.9	2.6	26.6	0.9	1.8	0.604	4.23	0
94	0	0.95	7.62	2.8	23.8	1	1.9	1.587	5.08	0
98	0.34	1.68	6.06	3.9	26.9	2	1.7	0.673	4.38	0
100	0.62	1.54	7.08	1.8	28.6	1.8	0.9	0	4.92	0.62
106	0.35	0.7	7.02	1.7	23.2	0.7	1.1	0.702	3.16	0
110	0	0	6.34	1.4	21.5	1.1	1.1	0.704	2.46	0
114	0	1.64	7.89	1	24.3	2	0.7	0	2.63	0.33
120	0	1.26	9.15	6.2	26.5	0.9	1.3	0	3.79	0.32
122	0	1.52	8.23	3.2	24.4	2.4	0.6	0	3.35	0.91
126	0	0.95	9.15	8.3	23.7	1.9	0.9	0	3.15	1.26
130	0	0.34	10.2	16	24.1	1.4	1.4	0	3.39	0.34
136	1.44	8.93	9.16	25	2.59	2	1.4	4.323	0.86	0.29

Hedrick Pond Pollen Percentages							
Depth (cm)	CARY	RUM	LYC	SPA	POT	MYR	NUP
0	0	0	0	0	0.35	0	2.82
4	0	0	0	0	0.33	0	2
8	0	0	0	0	0.31	0	1.56
10	0	0	0	0	0	0.41	1.66
12	0	0	0	0	0.58	0	2.34
16	0	0	0	0	0.57	0	2.56
20	0	0	0	0	0	0	0.72
30	0	0	0	0	0	0.46	0.46
35	0	0	0	0	0	0	0.47
40	0	0	0	0	0	0.4	0
44	0	0	0	0	0	0.65	1.94
50	0.369	0	0	0	0	0.36	0
53	0.683	0	0	0	0	0.66	0
56	0.336	0	0	0	0	0.66	0
60	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0
66	0.321	0	0	0	0	0	0
70	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0
80	0.338	0	0	0	0	0	0
82	0.326	0	0	0	0	0.64	0
86	0	0	0.3	0	0	0.57	0
90	0	0	0	0	0	0.58	0
94	0	0	0	0	0	0.92	0
98	0	1.01	0	0	0	0	0
100	0	0.62	0	0	0	0	0
106	0	0	0	0.34	0	0	0
110	0	0	0	0.35	0	0	0
114	0	0	0	0	1.6	0.32	0
120	0	0	0	0	4.21	0.56	0
122	0	0	0	0	1.72	0.86	0
126	0.315	0	0	0	2.49	1.39	0
130	0.339	0	0	0	1.91	1.09	0
136	0	0	0	2.04	0.51	0	53

Pothole Lake Pollen Percentages																						
Depth (cm)	P CONT	P ALB	P UNDIF	PIC	ABE	PSU	JUN	ALN	BET	SAL	POP	QUE	AME	ELE	EPH	SAR	POA	ART	AMB	TUB	LIG	CHEN
0	55.6	0	8.4	64	0	0.4	0	0	1.6	0.4	0	0	0	0	0.8	0	0	0.8	18	0.4	1.2	4.8
4	27.4611	0	4.66321	32	0	1.55	0	0	1	0	0	0	0	0	0	0.52	0	2.6	31.1	2.1	5.2	6.736
8	12.0253	0	2.53165	15	0	0.63	0	0	0	0	0	0	0	0	0	0.63	0	1.3	62.7	2.5	1.9	8.228
12	0	0	0	0	0	0	0	0	0.8	1.7	0	2.48	0	0	0	0	0	2.5	45.5	3.3	8.3	12.4
16	8.12183	0	1.52284	9.6	0	0	0	0	2	0.5	0	0	0	0	0	0	0	0	56.3	2	6.6	7.107
20	1.14943	0	0	1.1	0	0	0	0	4.6	6.9	6.9	6.9	0	1.1	0	0	1.15	13	29.9	5.7	3.4	5.747
24	8.08081	0	1.0101	9.1	0	0	0	1	0	0	0	2.02	0	0	0	0	0	3	57.6	3	6.1	7.071
28	4.62963	0	0	4.6	0.93	0	0	0	0	0.9	0	2.78	0	0	0	0	0	2.8	63	3.7	7.4	5.556
32	2.99401	0	1.1976	4.2	0	0	0	0	0	0	0	1.2	0	0	0	0	0	2.4	75.4	3	4.8	5.389
36	9.67742	0	2.41935	12	0	0	0	0	4	0	0	3.23	0	0	0	0.81	0	3.2	54	5.6	3.2	5.645
40	0	0	0	0	0	0	0	2	0	25	0	29.4	0	0	0	0	0	20	15.7	2	0	0
44	34.3373	0	6.62651	41	0.6	0	0	0	0	0.6	0.6	1.2	0	0	0	0	1.2	1.8	44	0.6	3	2.41
48	67.9558	0.2762	14.6409	83	0	3.59	0	3.3	0	0	0	0.55	0.28	0	0	0	0	1.1	6.08	0	0.3	0
50	46.2585	0	11.5646	58	0.68	0.68	0	0	0.7	0	0.68	0	0	0	0	0.68	0	1.4	32.7	2.7	0	0
54	71.3781	0	10.6007	82	0	0.35	0	0	0	0	0	0	0	0	0	0.71	0	3.2	12	0	0.7	0.707
58	64.1667	0	15.8333	80	0	0.83	0.4	0.8	0	0	1.25	0.83	0.42	0.4	0	0	0	2.1	8.75	0.4	0.8	1.25
62	66.0377	0	14.1509	80	0	1.89	0	1.9	0	0	0	0	0	0	0	1.89	0	3.8	4.72	0.9	0	1.887
66	73.5202	0	13.3956	87	0	0.93	0	0	0	0	0	0.31	0	0	0	0.62	0	2.8	7.48	0.3	0	0

Pothole Lake Pollen Percentages														
Depth (cm)	SALS	RAN	CARY	POLY	GIL	PTE	DRY	LYC	EQU	POT	NUP	BRA	ISO	DEG
0	2	0	0.8	1.2	0	0	2.4	1.2	0	0	0	0.4	0.4	0
4	6.218	0	0	9.845	0	0	0.52	0.5	0	0.52	0	0	0	0
8	5.696	0	0	1.899	0	0	0	0	0	0	0	0	0	0
12	13.22	0	0	9.917	0	0	0	0	0	0	0	0	0	0
16	6.599	0	0.508	6.599	0	0	2.03	0	0	0	0	0	0	0
20	6.897	0	0	3.448	0	1.1	2.3	0	0	0	1.11	0	0	2.22
24	8.081	0	0	3.03	0	0	0	0	0	0	0	0	0	0
28	2.778	0	0	2.778	1.9	0	0.93	0	0	0	0	0	0	0
32	2.395	0	0	0.599	0	0	0.6	0	0	0	0	0	0	0
36	3.226	0	0	0	0	0	4.03	0.8	0	0	0	0	0	0
40	5.882	0	0	0	0	0	0	0	0	0	0	0	0	0
44	2.41	0	0	0.602	0	0	0	0	0	0	0	0	0	0
48	1.105	0.55	0	0	0	0	0.28	0	0	0	0	0	0	0
50	1.361	0	0	0	0	0	0.68	0	0	0	0	0	0	0
54	0.353	0	0	0	0	0	0	0	0	0	0	0	0	0
58	1.25	0	0	0	0	0	0.42	0	0	0	0	0.82	0	0.82
62	0.943	0	0	0	0	0	1.89	0	0.92	0	0	0	0	1.83
66	0.623	0	0	0	0	0	0	0	0	0	0	0	0	0

Swan Lake Pollen Percentages																		
Depth (cm)	P CONT	P ALB	P UNDIF	PIC	ABE	PSU	JUN	ALN	BET	SAL	POP	QUE	ROS	SPI	AME	EPH	SAR	POA
0	55.0562	0	4.49438	60	21.9	3.37	0	0	0	0	3.37	0	0	0	0	0.56	0	0.56
3	58.216	0.4695	3.99061	63	32.9	0.23	0	0	0	0	0.7	0.23	0.47	0	0	0	0	0.23
6	71.6456	0.5063	7.8481	80	11.9	0.76	0.3	0	0	0	0.76	0	0	0	0	0	0	0
9	70.1183	0.5917	6.80473	78	16.6	0	0.6	0	0	0	2.07	0	0	0	0	0	0	0
13	48.3871	0.7168	2.50896	52	35.5	0.72	1.1	0	0.4	0	1.08	0	0	0	0	0	0	0.36
17	36.2398	0.2725	4.90463	41	48.8	1.09	0.5	0	0.5	0	1.63	0	0.27	0	0	0	0	0.27
20	74.5407	0	9.97375	85	2.62	1.31	0	0	0	0	0.52	1.31	0.26	0.3	0.52	0.26	0	0.26
23	60.8696	0	7.24638	68	17.6	2.36	0.2	0	0	0.2	1.81	0.91	0	0	0	0	0	0
26	43.956	0.8242	4.3956	49	30.5	2.75	0.3	0	0	0	0.82	0.55	0	0.5	0	0	0.27	0
29	34.0845	0.2817	3.94366	38	41.7	1.41	0	0	1.1	0	1.41	0.28	0	0	0	0	0	0
32	38.0062	0	4.04984	42	29.9	0.93	0	0	1.9	0.6	8.1	0	0	0	0	0.31	0	0.62
35	74.1176	0	8.23529	82	0	1.18	0	0	1.2	0	0	0	0	0	0	0	0	0
38	47.0968	0.9677	4.51613	53	26.8	0.32	0	0.3	1.9	0.6	3.55	0.97	2.26	0	0	0	0	0
41	73.7654	0.6173	10.4938	85	0	2.16	0	0.3	0.6	0.6	0.93	0	0	0	0	0	0	0.31
44	76.4599	0.365	6.56934	83	0	1.09	0	0.5	0	0	0.55	0.55	0	0	0	0.18	0	0
47	83.727	0.7874	5.77428	90	0.26	0.52	0	0	0	0	0.79	0.26	0	0	0	0.26	0.26	0
50	79.3319	1.0438	10.2296	91	0	1.04	0.2	0	0.4	0	0	0.21	0	0	0	0	0.21	0.21
53	70.0288	0.2882	8.64553	79	0.58	0.86	0	0.6	0	0.3	0.29	1.15	0	0	0	0	0	0.29
56	2.57235	0	0.96463	3.5	0	0	0	2.3	2.6	0.3	12.2	0	0	0	0	0	0	0.64
59	72.5067	0.2695	13.2075	86	0.27	1.62	0	0	0	0	0.27	0	0	0	0	0	0	0
62	3.98551	0	0.72464	4.7	0	0	0	0	2.2	0.7	2.54	0.72	0	0.4	0	0	0	0
65	5.46218	0	1.68067	7.1	0	0	0	0	1.7	0.8	3.36	2.1	0	0	0	0	0	0.84
68	24.9351	0	16.1039	41	1.82	0	0	0	1	0.5	2.34	1.82	0.26	0	0	0	0	0.26
71	7.09677	0	1.29032	8.4	0	0	0	0.3	0.6	0	0.32	0.32	0.32	0	0	0	0	1.61

Swan Lake Pollen Percentages															
Depth (cm)	MAL	ART	AMB	IVA	TUB	LIG	CHEN	SALS	RAN	UMB	CARY	POLY	RUM	PLAN	PTE
0	3.37	0	5.06	0.6	0	0.6	0	0.562	0	0	0	0	0	0	0.6
3	0.23	0	1.64	0.7	0	0	0	0	0	0	0	0	0	0	0
6	0.25	0	4.56	0	0	0.3	0	0.759	0	0	0	0	0	0	0
9	0.89	0	1.18	0.3	0	0	0	0.296	0	0	0	0	0	0	0
13	1.79	0	3.58	0	0	1.4	0	1.792	0	0	0	0	0	0	0
17	0.27	0	3.54	0	0	0	0	1.09	0	0	0	0	0	0	0
20	0	0	5.77	1.3	0	0	0	0.787	0.26	0	0	0	0	0	0
23	0.72	0	6.52	0.5	0	0	0	0.725	0	0	0.181	0	0.18	0	0
26	2.2	0	10.2	0.5	0	0.3	0	1.923	0	0	0	0	0	0	0
29	0	0.3	9.86	0	0	1.4	0	3.099	0.28	0	0	0	0	0.563	0
32	0	0	7.17	1.2	0	1.6	0	2.492	1.25	0	0.623	0	0.62	0	0
35	0	0	12.9	0	0	1.2	0	1.176	0	0	0	0	0	0	0
38	0.32	0	8.06	0.3	0	0	0	1.935	0	0	0	0	0	0	0
41	0.93	0	5.25	0.6	0	0	0	2.469	0	0	0	0	0	0	0
44	0	0	10.2	0.5	0	0.2	0	1.095	0.18	0	0	0	0	1.277	0.2
47	0.52	0	5.25	0	0	0	0	1.312	0	0	0	0	0	0	0
50	0	0	5.64	0	0	0.6	0	0.626	0	0	0	0	0	0	0.2
53	0	0.3	9.51	1.2	0	2	0	2.882	0	0	0	0	0	0	0
56	0.32	0	46.6	2.6	0.6	0.3	0.322	5.466	0	0	0	0	1.61	0	0
59	0.81	0	9.97	0	0	0	0	1.078	0	0	0	0	0	0	0
62	1.81	0	56.2	3.6	0	0	0.362	16.3	1.09	0.36	0	0	4.35	2.536	0.7
65	0.84	0	59.2	1.7	0	1.3	0.42	12.61	3.78	0	0	0	0	3.782	0.4
68	0.26	0	39.7	1.6	0	0.3	0.26	6.753	0.26	0	0	0	0	1.558	0.3
71	0.65	0	67.7	1.6	0	1.6	0	11.29	1.94	0	0	0.323	0	0	0

Swan Lake Pollen Percentages											
Depth (cm)	DRY	LYC	BOT	UNK	EQU	SPH	POT	NUP	P AMPH	ISO	DEG
0	0	0	0	0	0	0	0	1.11	0	0	0
3	0	0	0	0	0	0	0	0.93	0	0.2	0
6	0.51	0	0	0	0.25	0	0	0.75	0	0	0.25
9	0.59	0	0	0	0.29	0	0	0.88	0	0	0
13	0.72	0	0	0	0	0	0	1.76	0	0	0
17	0	0.5	0	0	0.27	0	0	1.33	0	0.3	0.27
20	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0.36	0	0	0
26	0	0	0	0	0	0	0	1.09	0	0	0
29	0.28	0	0	0	0.55	0	0	0.82	0	0	1.1
32	0.62	0	0.3	0	0.3	0	0	0.61	0	0.3	0.91
35	0	0	0	0	1.16	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0.31	0	0	2.2
41	0.93	0	0	0	0	0	0	0	0	0.3	0.61
44	0	0	0	0	0	0	0	0	0	0	0
47	0.26	0	0	0	0	0	0	0.52	0	0	0
50	0	0	0	0	0	0	0	1.64	0	0	0.2
53	0.58	0.6	0	0	0	0	0	0	0	0	0.29
56	18	2.6	0	0	0	0	0	0	0.31348	0	2.19
59	0	0	0	0	0	0.27	0	0.53	0	0	0
62	0.36	1.1	0	0	0.34	0	0	0.34	0	0	5.44
65	0	0	0	0	0	0.4	1.2	0	0	0	3.59
68	0	0	0	0	0.76	0	0	0.25	0	0	1.27
71	1.61	1.3	0	1.53	2.14	0	0.61	0	0	0	0.92

APPENDIX D:

CHARCOAL CONCENTRATIONS AND ACCUMULATION RATES

Hedrick Pond		
Depth (cm)	Charcoal Concentration[1]	Charcoal Accumulation Rate[2]
0	0	0
1	0.66667	0.203
2	1.33333	0.378
3	0.33333	0.088
4	0.33333	0.083
5	0.66667	0.157
6	1.33333	0.298
7	1	0.212
8	0	0
9	0.33333	0.064
10	0.66667	0.123
11	0	0
12	0	0
13	0.33333	0.055
14	0	0
15	0.33333	0.051
16	0.66667	0.099
17	0.33333	0.048
18	0	0
19	1.33333	0.179
20	0.66667	0.087
21	0.66667	0.085
22	0.33333	0.041
23	0	0
24	1	0.118
25	0.33333	0.038
26	2	0.224
27	3	0.328
28	1.66667	0.178
29	1.33333	0.139
30	2.33333	0.239
31	2.66667	0.267
32	7.33333	0.721
33	2.66667	0.257
34	1.33333	0.126
35	1	0.093
36	2.33333	0.213
37	3	0.268

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[1] Concentration in particles cm^{-3}

[2] Accumulation rate in particles cm^{-2} yr^{-1}

Depth (cm)	Charcoal Concentration	Charcoal Accumulation Rate
39	1.66667	0.144
40	2	0.17
41	0.33333	0.028
42	0	0
43	1	0.081
44	1	0.08
45	2.66667	0.21
46	0.33333	0.026
47	1	0.076
48	0.66667	0.05
49	2.33333	0.173
50	2	0.147
51	1.33333	0.096
52	2.33333	0.167
53	3.66667	0.259
54	3	0.209
55	2.33333	0.161
56	2.33333	0.159
57	6.33333	0.426
58	5.33333	0.354
59	3.33333	0.219
60	7	0.455
61	6.33333	0.407
62	3.66667	0.233
63	4.33333	0.272
64	2.66667	0.166
65	1.66667	0.103
66	1.33333	0.081
67	0.66667	0.04
68	1	0.06
69	1	0.059
70	3	0.176
71	1.33333	0.078
72	1	0.058
73	2.66667	0.152
74	1	0.057
75	0.66667	0.037
76	1	0.056
77	2	0.11
78	4	0.219
79	3.33333	0.181
80	2.66667	0.144
81	6	0.321

Depth (cm)	Charcoal Concentration	Charcoal Accumulation Rate
82	3.33333	0.177
83	2.66667	0.14
84	1	0.052
85	1	0.052
86	1.66667	0.086
87	0.66667	0.034
88	1.33333	0.068
89	2.66667	0.135
90	7	0.351
91	0.66667	0.033
92	2	0.099
93	0.33333	0.016
94	1.66667	0.081
95	2.33333	0.113
96	3.33333	0.161
97	3.33333	0.16
98	2	0.095
99	5.33333	0.253
100	3	0.141
101	4.33333	0.203
102	4.33333	0.202
103	1	0.046
104	1.33333	0.061
105	1.33333	0.061
106	3	0.137
107	4.66667	0.212
108	4	0.18
109	2.33333	0.105
110	1	0.045
111	1	0.044
112	1	0.044
113	2.33333	0.103
114	3.66667	0.161
115	5.33333	0.233
116	9.33333	0.405
117	3.33333	0.144
118	5.66667	0.244
119	5	0.214
120	8.33333	0.356
121	5.33333	0.227
122	5.66667	0.24
123	2	0.084
124	3.66667	0.154

Depth (cm)	Charcoal Concentration	Charcoal Accumulation Rate
125	1	0.042
126	1.33333	0.056
127	2	0.083
128	3	0.124
129	5	0.206
130	5.66667	0.233
131	6	0.246
132	9	0.367
133	7.66667	0.312
134	2.33333	0.095
135	2	0.081
136	7.66667	0.309
137	5	0.201
138	7.66667	0.497

Pothole Lake Charcoal Counts		
Depth (cm)	Charcoal Concentration	Charcoal Accumulation Rate
0	0.5	0.1743
1	0.25	0.0754
2	0.75	0.1981
3	0.5	0.1169
4	1.25	0.2607
5	0.75	0.1406
6	0.5	0.0848
7	0.25	0.0386
8	0.5	0.0706
9	0	0
10	0.5	0.0598
11	0	0
12	1.75	0.1797
13	0.25	0.0239
14	0.25	0.0223
15	1.5	0.1253
16	1	0.0784
17	1.25	0.0921
18	1.25	0.0868
19	0.75	0.0491
20	0	0
21	1.5	0.088
22	1.75	0.0974
23	5	0.2642
24	6	0.3016
25	0.75	0.0359
26	2.25	0.1027
27	0.75	0.0327
28	0.5	0.0208
29	3	0.1196
30	0.25	0.0095
31	0.25	0.0091
32	0.5	0.0176
33	3	0.1011
34	0	0
35	0.75	0.0234
36	1	0.03
37	2.25	0.065
38	3	0.0836
39	0.25	0.0067
40	0.75	0.0195

Depth (cm)	Charcoal Concentration	Charcoal Accumulation Rate
41	3.5	0.0877
42	2	0.0484
43	1.25	0.0293
44	1.25	0.0283
45	3	0.0658
46	6.25	0.1329
47	4.75	0.0979
48	1.5	0.03
49	0.25	0.0048
50	3.75	0.0705
51	4	0.0731
52	2.75	0.0488
53	2.25	0.0388
54	0.25	0.0042
55	2	0.0326
56	2.25	0.0357
57	1	0.0154
58	1.25	0.0188
59	4.5	0.0659
60	0.75	0.0107
61	1.5	0.0209
62	1.25	0.017
63	2.5	0.0331
64	1	0.0129
65	1	0.0126
66	3.25	0.1004

Swan Lake Charcoal Counts		
Depth (cm)	Charcoal Concentration	Charcoal Accumulation Rate
0	1.33333	0.4959
1	0.33333	0.0957
2	1	0.3244
3	5	2.3564
4	3.66667	2.9769
5	4	3.8355
6	2	0.9146
7	2.66667	0.5037
8	2.66667	0.2425
9	2	0.1004
10	1	0.0306
11	3	0.4165
12	2	0.2456
13	1	0.1228
14	1	0.1228
15	2	0.2456
16	2	0.2456
17	1.66667	0.2046
18	4.66667	0.573
19	0.66667	0.0819
20	1.33333	0.1637
21	1.66667	0.2046
22	2	0.2456
23	3.66667	0.4502
24	3	0.3684
25	3.66667	0.4502
26	5.66667	0.6958
27	4.33333	0.5321
28	2.66667	0.3274
29	4.66667	0.573
30	3.66667	0.4502
31	1	0.1228
32	2	0.2456
33	0.66667	0.0819
34	0.66667	0.0819
35	0.33333	0.0409
36	0	0
37	0.33333	0.0409
38	0	0
39	0	0
40	1.66667	0.2046

Depth (cm)	Charcoal Concentration	Charcoal Accumulation Rate
41	1.66667	0.2046
42	0	0
43	0	0
44	1	0.1228
45	0.66667	0.0819
46	2.33333	0.2865
47	1	0.1228
48	1.33333	0.1637
49	1	0.1228
50	3.66667	0.4502
51	1.66667	0.2046
52	0.66667	0.0819
53	6	0.7367
54	2.66667	0.3274
55	5.66667	0.6958
56	9	1.1051
57	6	0.7367
58	2.66667	0.3274
59	4.33333	0.5321
60	7.66667	0.9414
61	16.3333	2.0055
62	6	0.7367
63	8.66667	1.0642
64	8	0.9823
65	19	2.333
66	17.3333	2.1283
67	9.66667	1.187
68	9.33333	1.146
69	9	1.1051
70	8	0.9823
71	11.6667	1.4325
72	10.3333	1.2688
73	12.3333	1.6799