

LATE HOLOCENE VEGETATION AND FIRE HISTORY IN SUBALPINE FORESTS
OF NORTHWESTERN MONTANA

by

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ABSTRACT

Mid-to high- elevation forests of the Northern Rocky Mountains are dynamic systems that change in time in response to climate, disturbance and human activities. Climate models suggest these ecosystems will experience warmer temperatures, decreased spring snowpack, drier summers, and longer fire seasons, highlighting a need to better understand how these systems respond to changing climatic conditions. Sediment cores were extracted from two lakes in the Mission and Reservation Divide Mountains of Montana and analyzed for pollen and macroscopic charcoal to reconstruct fire and vegetation histories. The records from Mud Lake and Three Lakes Peak span the last 5400 and 4600 years respectively, and highlight the long-term persistence and relative stability of closed, mixed conifer/subalpine forests. During the mid-Holocene (approx. ca. 5000 yr BP), *Pinus* pollen percentages increased, suggesting closed forests which then transitioned to mesic forest of *Pinus*, *Abies*, and *Picea* over the last ca. 4000 years. Modern forests established between 3500-3000 cal yr BP at both sites. Both sites experience elevated fire activity during the Medieval Climate Anomaly c. 1000-900 cal yr BP which is consistent with other sites in the region. While relatively infrequent (2-4 fires per millennia), wildfires played a role in maintaining early successional vegetation (*Poaecaeae*, *Alnus* spp.) and taxa that benefit from post-fire reduction in competition such as five-needle pines. Paleoenvironmental records from these two sites indicate subalpine forests of northwestern Montana persisted with relative stability throughout the mid to late-Holocene. With projections for increased warming, longer fire seasons and the possibility for increased occurrence of short-interval fires in higher elevation ecosystems of the Northern Rocky Mountains, subalpine forests may become vulnerable to rapid transitions to different forest types or even non-forest systems.

INTRODUCTION

Changing climate conditions and land-use patterns are impacting ecosystems and disturbance regimes globally, and these trends are expected to continue into the future (Burke et al. 2019). Over the last several decades, these changes have caused a substantial increase in wildfire activity in temperate and coniferous forests of the western US, where the US Government spends over \$1 billion annually on fire-fighting efforts (Harvey et al. 2016, Whitlock et al. 2003). Increased fuel loads in some forests, resulting from 20th century fire suppression efforts along with extended fire seasons have also increased the frequency of large fire events and in some instances, increased fire severity (Schoennagel et al. 2017).

The Northern Rocky Mountains (NRM) are thought to be especially vulnerable to increases in fire activity due to warming temperatures (Higuera et al. 2015). Most precipitation in high-elevation forests of the region falls during winter as snow, and snowpack is of critical importance for summer fire activity (Carter et al., 2017). Reduced snowpack can lead to summer droughts that promote wildfire activity in forests typically too moist to burn frequently. With projected decreases in snowfall in the coming decades, along with projected warming spring and summer temperatures, high-elevation forests of the Northern Rockies are susceptible to increases in fire activity (Westerling et al., 2016; Carter et al. 2017).

Recent warming in Montana has already resulted in conditions conducive to fire ignition and spread. Reduced annual snowpack, earlier onset of spring snowmelt,

increased frequency of extreme high temperatures and reduced summer stream flow have all contributed to an increase in the length of the fire season (Pederson et al. 2010). This shift in fire activity is occurring rapidly and has the potential to dramatically alter forest structure and composition, with important consequences to critical ecosystem services including carbon storage, water quality and quantity, nutrient cycling and wildlife habitat (Harris et al. 2016).

Although there are several postglacial fire and long-term vegetation histories in NRM forests (Power et al. 2011; Alt et al., 2018; Mack et al., 1983), there are few records from mid-elevation (1400-2400 masl) mixed-conifer forests in northwest Montana. In the NRM, mixed-conifer parkland and subalpine forests consisting of *Pinus*, *Abies* and *Picea* have dominated mid to high elevations during the course of the Holocene (Carter et al., 2017). Vegetation change in the region following early-Holocene warming is thought to have been fire-facilitated, as rising temperatures fostered increased fuel loads and therefore increased fire (Krause & Whitlock., 2012). Mid- to high-elevation forests of northwest Montana currently experience variable fire regimes, with fires (2-13 episodes per 1000 yrs.) of varying intensity, size, and burn severity (Millspaugh et al., 2000; Alt et al 2018). Highly variable fire regimes have resulted in heterogenous forest stands with mesic and xeric forest types co-occurring in close proximity. These complex fire regimes and forest mosaics are not well studied compared to low-severity mixed-conifer forests and fire regimes such as *Pinus ponderosa* parklands (Schoennagel et al. 2004).

Many subalpine forests in the NRM are home to whitebark pine (*Pinus albicaulis*) (WBP), a keystone species that provides important food resources (e.g., pine nuts) for a number of animals. WBP populations are currently decreasing throughout their historical range due to increases in native mountain pine beetle (*Dendroconus ponderosae*) outbreaks, mortality from non-native white pine blister rust (*Cronartium ribicola*), competition from spruce (*Picea engelmannii*) and fir spp. (*Abies*) (Larson et al., 2015), as well as changes in fire activity that has allowed subalpine competitors such as *Abies* and *Picea* to expand at the expense of whitebark pine. The distribution of WBP populations are strongly linked to treeline environments. These bioclimatic settings where WBP dominate are currently experiencing rapid warming. As a result, models suggest that WBP are particularly vulnerable to “mountain top extinctions”, where the most optimal bioclimatic conditions move upslope under projected future conditions, greatly decreasing, if not eliminating, suitable climates (Hansen et al., 2016).

The long-term ecosystem dynamics of WBP are less well understood than other arboreal species in the region. It is unclear how continued climate warming will affect WBP in northwestern Montana. Warming could inhibit WBP through intense fire activity, drought, insect activity and increased interspecific competition from spruce, fir and lodgepole pine or facilitate WBP through upslope tree line expansion and infill and moderate fire activity, promoting the establishment of new WBP stands. Direct impacts will result from shifts in temperature and precipitation patterns, and indirect impacts through climates’ influence on WBP’s limiting factors such as fire, competition, and insect disturbance (Hansen et al., 2016).

The primary goal of this study is to reconstruct the vegetation and fire history in two subalpine watersheds in the Mission and Reservation Divide mountains of northwestern Montana, based on pollen and charcoal analysis of lake sediments from two subalpine lakes. This research aims to improve our understanding of how changes in climatic conditions and disturbance regimes projected for the future might impact high-elevation forests in the coming decades. Valuable insight can be gained from paleoecological reconstructions to guide future land restoration and management decisions.

The objectives of this study are as follows:

- I. Reconstruct millennial-scale vegetation and fire history in two subalpine watersheds in northwestern Montana
- II. Compare these records with nearby low- and mid-elevation sites in the Flathead region
- III. Compare these records with other high elevation paleoenvironmental records from the northern Rocky Mountains

Site Description

The two study sites both exist within the bounds of the reservation lands of the Confederated Salish and Kootenai Tribes (Figure 1). The Reservation Divide mountains run roughly northwest to southeast and mark the southwestern border of the Flathead Reservation. Ch-paa-qn Peak is the highest point of the range with an elevation of 2437 masl. The north-to-south trending Mission Range marks the eastern border, with the

highest elevation of 2990 masl at McDonald Peak. Alpine glaciers formed in the Missions during the Last Glacial Maximum (LGM; 26,000-19,000 cal yr BP), as the southwest margin of the Cordilleran Ice Sheet spilled into the northernmost part of the range (Davis 2016).

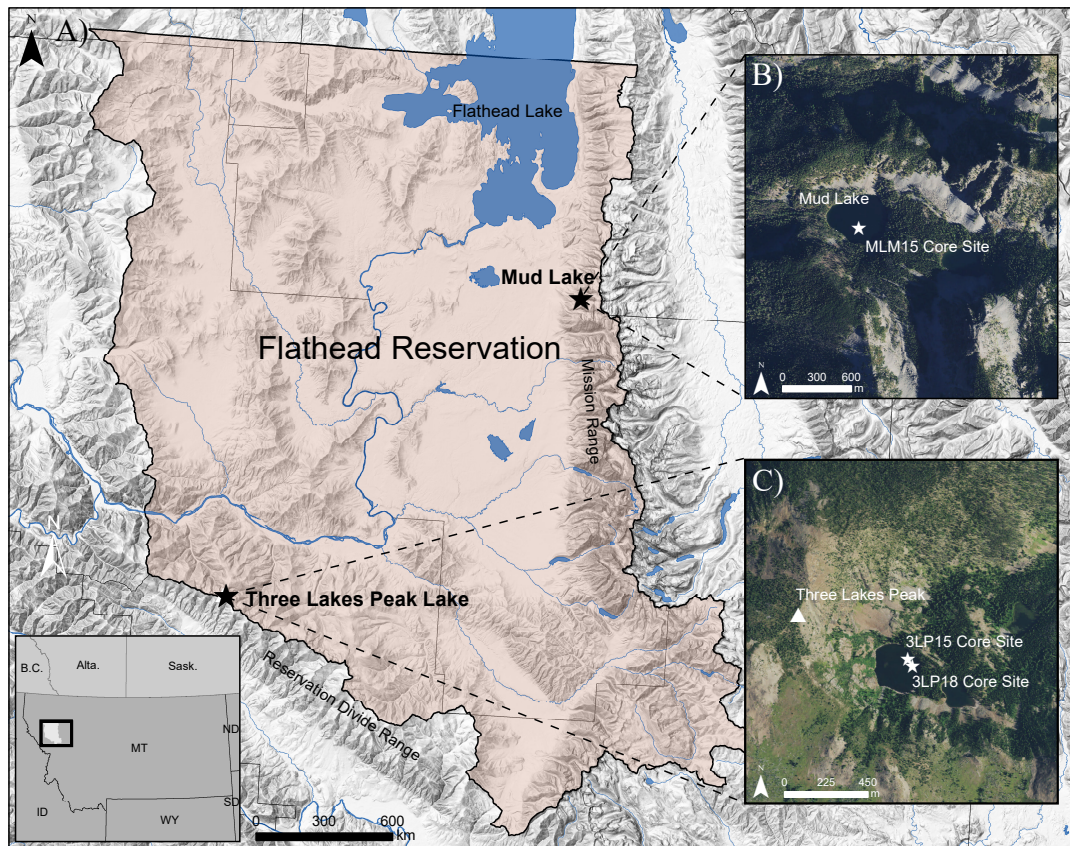


Figure 1. A) Map of study sites in the Mission and Reservation Divide mountains (Map source Montana State Library at montana.gov) B) Aerial image of Mud Lake including MLM15 coring location (Map source Montana State Library at montana.gov). C). Aerial image of Three Lakes Peak Lake including 3LP15 and 3LP18 coring location (Map source Montana State Library at montana.gov).

Mud Lake (1765 masl), is the lowest of several small lakes in the glacial cirque just north of Goat Peak in the Mission mountains (Figure 1A.). The cirque is drained by Mud Creek, which flows into the Mission Valley below. Mud Lake is of great cultural significance to the Confederated Salish-Kootenai Tribes.

Three unnamed lakes lie beneath Three Lakes Peak (2375 masl) in the Reservation Divide mountains. For this study, sediments were obtained from the largest of the three lakes, called Three Lakes Peak Lake (hereafter referred to as 3LP Lake, 2072 masl).

Climate variability serves as the primary control on vegetation and fire activity at millennial scales through the Holocene (Power et al., 2011). Shifts in vegetation mediate climate's impact on fire regimes by altering fuel abundance and forest structure (Higuera et al., 2009). Following the Last Glacial Maximum, retreating ice sheets at high elevations and latitudes, rising concentrations of greenhouse gasses in the atmosphere and changes in seasonal and latitudinal insolation variations drove climate change in the northern hemisphere over the Holocene (Alder and Hostetler, 2015). During the early Holocene (ca. 11,000 cal yr BP), paleoclimate models of the NRM show temperatures were 0.5-2°C higher than today as seasonal temperature extremes were amplified (Bartlein et al., 1998). By the mid-Holocene (approx. ca. 6000 BP) as summer insolation decreased towards modern levels, summer temperature decreased and winter temperature increased (Routsen et al., 2019).

Fire activity in the region saw increases during the mid-Holocene likely because wetter conditions promoted an increase in forest cover and fuel loads (Carter et al., 2017).

Regional charcoal data show two main increases in fire activity synchronous across sites from low to high elevation; at about 2000 cal yr BP and 5000-6000 cal yr BP (Brunelle et al. 2005; Alt et al. 2018; Benes et al., 2019). Some high-elevation sites also saw synchronous increases in fire activity around 900 cal yr BP (Carter et al., 2017).

Present Climate

The climate in the Northern Rocky Mountains is influenced by moisture-rich maritime air masses from the Pacific Coast that, via orographic processes, result in abundant precipitation at higher elevations (Parrett 1997). Average December minimum temperatures at Mud Lake and 3LP are -8.6°C and -10°C respectively. Average maximum summer temperatures occur in July, reaching 21.2°C at Mud Lake and 19.6°C at 3LP Lake (PRISM Climate Group).

Most annual moisture in both ranges arrives as snow during the winter months, brought by storm systems originating over the Pacific Ocean. During the summer months, local convective storms are the main source of precipitation as the northeastern Pacific subtropical high-pressure system limits the formation of storms over the Pacific. The western side of the Mission Range receives approximately 76 to 254 cm of precipitation annually, depending on elevation above the valley floor (Slagel 1988). 30-yr climate averages recorded from 1981-2010 show Mud Lake receives an average 127 cm of precipitation annually, while 3LP Lake averages around 110 cm (PRISM Climate Group, 2020).

Present Vegetation

The mountain ranges of northwestern Montana lie at the intersection of maritime and continental climatic regimes that support diverse assemblages of taxa from wetter maritime ecosystems of the Pacific Northwest and drier taxa found within the Rocky Mountains. Below the Mission and Reservation Divide mountains grasslands dominate valley bottoms and lower tree line is around 1060 masl. Wetter forest canopy dominants include: *Tsuga heterophylla*, *T. mertensiana*, *Thuja plicata*, *Abies grandis*, and *Pinus monticola* (Arno, 1979). Drier forest canopy dominants include: *Pseudotsuga menziesii* and *Pinus ponderosa*. In mesic zones at low to mid elevation, forests are composed of *Picea engelmannii*, *Pinus contorta*, *Larix occidentalis*, *Abies grandis*, *Thuja plicata* and *Pinus monticola*. From 1700 m to 2400 m, subalpine forest taxa are *Abies lasiocarpa* and *Picea engelmannii* (Arno, 1979). Approaching upper tree line anywhere from 2400 to 2700 m elevation, *Pinus albicaulis* and *Larix lyallii* form subalpine parklands (Pfister, 1977). Above these forests lies alpine tundra with taxa like *Carex spp.*, *Salix spp.*, and *Dryas spp.* (Montana Natural Heritage Program). Three Lakes Peak Lake is surrounded by a subalpine *Abies/Picea* forest while Mud Lake lies between mixed conifer and subalpine forests dominated by *Pseudotsuga*, *Pinus*, *Abies*, and *Picea*. *Pinus albicaulis* currently exists in the subalpine parklands above both Mud Lake and 3LP Lake.

Modern Fire Regime

Fire is an important ecosystem process in the NRM that forests have adapted to for thousands of millennia (Riley & Loehman et al. 2016, Whitlock et al. 2003, Huerta et al. 2008). Traits like resistance to fire via thick bark, or post-fire establishment through abundant seeding via serotinous cones help trees survive and reproduce following fire (Iglesias et al., 2014). Fire regimes in both the Mission and Reservation Divide mountains range from low, mixed, to high-severity depending on elevation and microclimatic gradients. Low-elevation NRM grasslands and *P. ponderosa* and *Pseudotsuga* parklands (800-1400 masl) experience frequent, low-severity surface fires (Swaney 2005). At mid to high elevations (1400-2400 masl), microclimate and topography promote diverse fire regimes and forest types and structure. This results in mixed-severity fire regimes where both frequent low-severity surface fires and infrequent high-severity stand-replacing fires are possible (Whitlock et al. 2003, Rocca et al. 2014). High-elevation subalpine forests often are moist and cool enough to burn infrequently, but with high-intensity and mortality. Over the last 2000 years, fire activity in the western US has primarily tracked climate variability, until the last two centuries when land-use change acted as a strong control on fire activity (Marlon et al. 2012).

METHODS

Core Collection

In June 2015, a 94.5-cm-long, 50 mm in diameter sediment core (MLM15) was obtained from Mud Lake in 5.2 meters of water with a modified polycarbonate piston corer. The polycarbonate tube was capped and sealed onsite for transportation and storage. In July 2015, one 85-cm-long sediment core (3LP15) was extracted from Three Lakes Peak Lake. In August, 2018, 3 core sections (3LP18 A, B, C; hereafter referred to as 3LP15/18 when referred to together with 3LP15) were collected in 3.35 m deep water with a modified Livingstone square-rod piston coring device (Wright et al. 1983). The first drive (Drive A) began approximately 30 cm below the mud-water interface and recovered 90 cm of sediment. Drives B and C were 58.5 and 47 centimeters long. Core sections were wrapped in plastic wrap and tinfoil and protected in PVC tubes for transport to the cold storage room at Montana State University.

Laboratory

MLM15 was split at the National Lacustrine Core Facility (LacCore) located at the University of Minnesota. Drives A, B, and C from 3LP18 were split longitudinally, photographed, and analyzed for visible lithological changes at the Montana State University Paleoecology Lab. Magnetic susceptibility (MS), charcoal and pollen was analyzed at 1.0-cm intervals. Lithology, charcoal values and radiocarbon dates were used

to match core 3LP15 and core sections from 3LP18 to create a continuous record for 3LP Lake. Drive A from 3LP18 was matched to 3LP15 at 31cm.

Charcoal

The top 50 cm of MLM15 was subsampled at 0.5 cm intervals for charcoal analysis, then at 1.0 cm intervals for the bottom 45.5 cm. All four core sections from 3LP15/18 were subsampled at 1.0 cm intervals. The preparation and counting procedures outlined by Whitlock and Larson (2001) served as a guide for the charcoal analysis of 3LP15/18 and MLM15. At each interval, 2 cm³ samples were deflocculated by soaking in bleach and sodium metaphosphate for 24 hours. The mixture was then sieved through a 125- μ m screen, and charcoal particles with a diameter greater than 125- μ m were counted under a stereomicroscope. This particle size was selected because previous research shows that charcoal particles larger than this represents local fire activity (<3km surrounding the site, Whitlock and Larson 2001).

Following the methods outlined by Higuera et al. (2009), the CharAnalysis program (<https://sites.google.com/site/charanalysis/>) was used to identify individual fire events at Mud Lake and Three Lakes Peak Lake. Charcoal Accumulation rates (CHAR; particles cm⁻²yr⁻¹) were calculated from raw charcoal counts. CharAnalysis uses raw charcoal counts to estimate background charcoal (BCHAR) representing secondary charcoal deposited from the watershed and extra-local fires (Whitlock and Larson 2001). A smoothing window of 800 years for peak detection was chosen to optimize the signal-to-noise ratio. A locally-defined threshold determined values that represented significant

fire peaks. A 1000-yr window was selected to smooth fire frequency and fire return intervals.

Pollen

1 cm³ samples were extracted at approximate 4-cm intervals from each core for pollen analysis. Pollen was processed utilizing the procedural outline of Bennett and Willis (2001). A tablet with a known concentration of *Lycopodium* spores was added to each sample in order to calculate pollen accumulation rates (PAR; grains cm⁻³ yr⁻¹) and pollen concentration (grains cm⁻³). Pollen material was spread on microscope slides with silicon oil, and a minimum of 300 terrestrial grains was identified to the lowest taxonomic level possible and counted at 400 to 1000x magnifications. Reference slides and pollen identification books (Faegri and Iversen, 1989; Kapp et al., 2000) were used to assist identification. Percentages of terrestrial pollen counts were calculated based on the terrestrial sum, and aquatic percentages were calculated based on the terrestrial and aquatic pollen sums.

The Mission and Reservation Divide ranges contain multiple species of *Pinus*. The lowest taxonomic level of identification possible within this genus is *Pinus* subgenus *strobis* and *Pinus* subgenus *Pinus*. *Pinus* subgenus *strobis*, hereafter referred to as Haploxyton-type *Pinus* are distinguishable by the presence of verrucae on the distal membrane, and is attributed to *P. albicaulis*, *P. flexilis*, and/or *P. monticola* in this region. *Pinus* subgenus *Pinus*, hereafter referred to as, Diploxyton-type *Pinus* grains were likely produced by *P. contorta* or *P. ponderosa*. *Pinus* grains with missing or damaged distal

membranes were counted as undifferentiated *Pinus*. *Picea* grains were attributed to *Picea engelmanni*. *Abies grandis* and *A. lasiocarpa* were ascribed from *Abies* pollen. *Pseudotsuga menziesii*, *Larix lyallii*, and *L. occidentalis* were counted together as *Pseudotsuga/Larix* as their grains are visually indistinguishable. *Cupressaceae* grains were resultant from *Thuja plicata*, *Juniperus communis*, and/or *J. scopularum*. Pollen counted as 'Rosaceae' includes grains of *Prunus*, *Sorbus*, and *Spiraea*. Damaged or unidentifiable grains were counted as 'Indeterminant' for terrestrial grains and 'Unknown Aquatic' if determined to be an unidentifiable aquatic grain.

RESULTS

Lithology

MLM15 was primarily composed of brown gyttja, with slight layering of lighter and darker brown bands of gyttja throughout the length of the core (Fig. 2). The uppermost band of dark gyttja from about 20-45 cm depth aligns with a period of slower sedimentation shown in the MLM15 age depth model from 4000-1000 cal yr BP (Fig. 3). The bottom of the core consisted of 1-2 cm of lighter sand, followed by approximately 2 cm of silty clay. 3LP15 and 3LP18 cores were primarily composed of dark brown gyttja with little variation in lithology.

The MLM15 magnetic susceptibility record indicates only minor erosion events inferred from the lack of prominent peaks and minimal variation. During the period of rapid sedimentation ca. 2100 to 800 cal yr BP, there is little change in lithology or magnetic susceptibility. The significant peak in magnetic susceptibility at the bottom of the record matches the sandy unit. Magnetic susceptibility values for 3LP15/18 record are relatively constant throughout the core sections.

Chronology

The 3LP18 cores were coordinated based on field notes in addition to charcoal and radiocarbon date matching. A chronology for MLM15 was created based on nine accelerator mass spectrometry (AMS) ^{14}C dates from bulk sediment (Fig 3.) (Table 1). The age-depth program Bacon identified one date as an outlier, and thus it was not

included in the final model. The sedimentation accumulation rate declined from 20-45 cm in MLM15 but there were no obvious changes in the lithology or magnetic susceptibility values associated with this decline. The 3LP15 and 3LP18 cores were matched using charcoal, lithology and radiocarbon dates from 13 AMS from bulk sediment (Fig 4.). One date at 48 cm depth was identified as an outlier was not included in the final 3LP15/18 chronology. The sedimentation rate for 3LP15/18 stays fairly consistent throughout. The ^{14}C dates were converted to calendar years using Calib 7.10 software with the IntCal13 calibration curve (Reimer et al., 2013), and the final age-depth model was derived using Bacon age-depth program (Blaauw and Christen, 2011) in R (R Core Team, 2015). Basal dates for 3LP18 C dated to 4140 ± 20 , and the deepest sample of MLM15 to 4499 ± 25 .

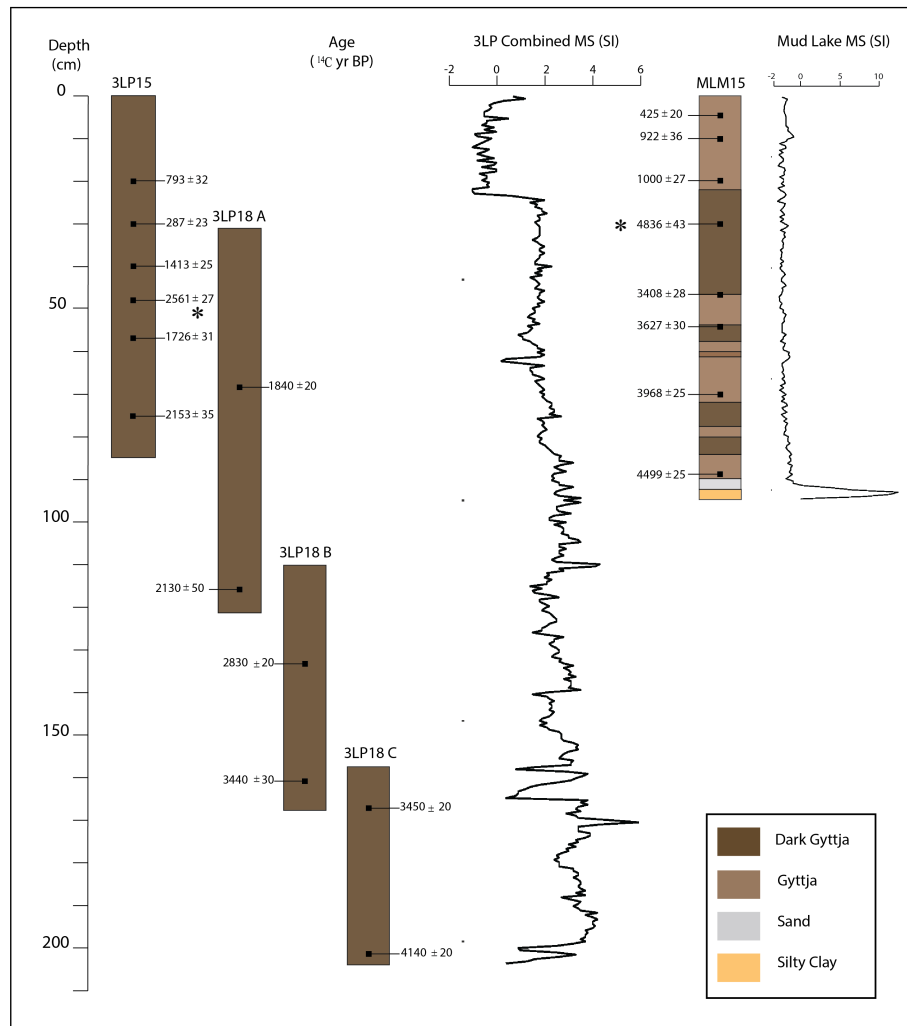


Figure 2. Diagram of sediment cores from Three Lakes Peak Lake (3LP15 and 3LP18 A, B, and C) and Mud Lake (MLM15), the locations of uncalibrated radiocarbon dates, and magnetic susceptibility profiles for both records. Dates marked with an asterisk indicate outliers that were not included in the final age depth model.

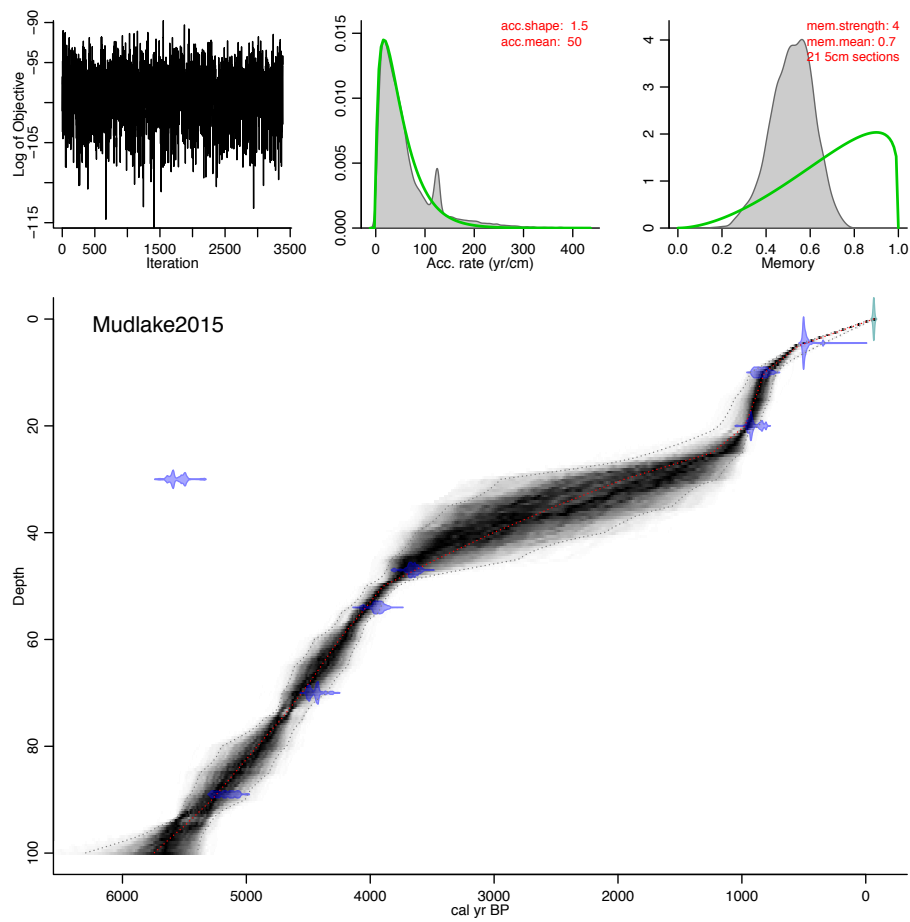


Figure 3. Age-depth model of Mud Lake. The red line shows the interpolated age for each depth of the core, while the grey shading represents the 95% confidence interval. The blue shapes show calibrated radiocarbon dates and the horizontal bars show their error. The date at 30 cm was identified by the Bacon age-depth model as an outlier and therefore excluded from the final model.

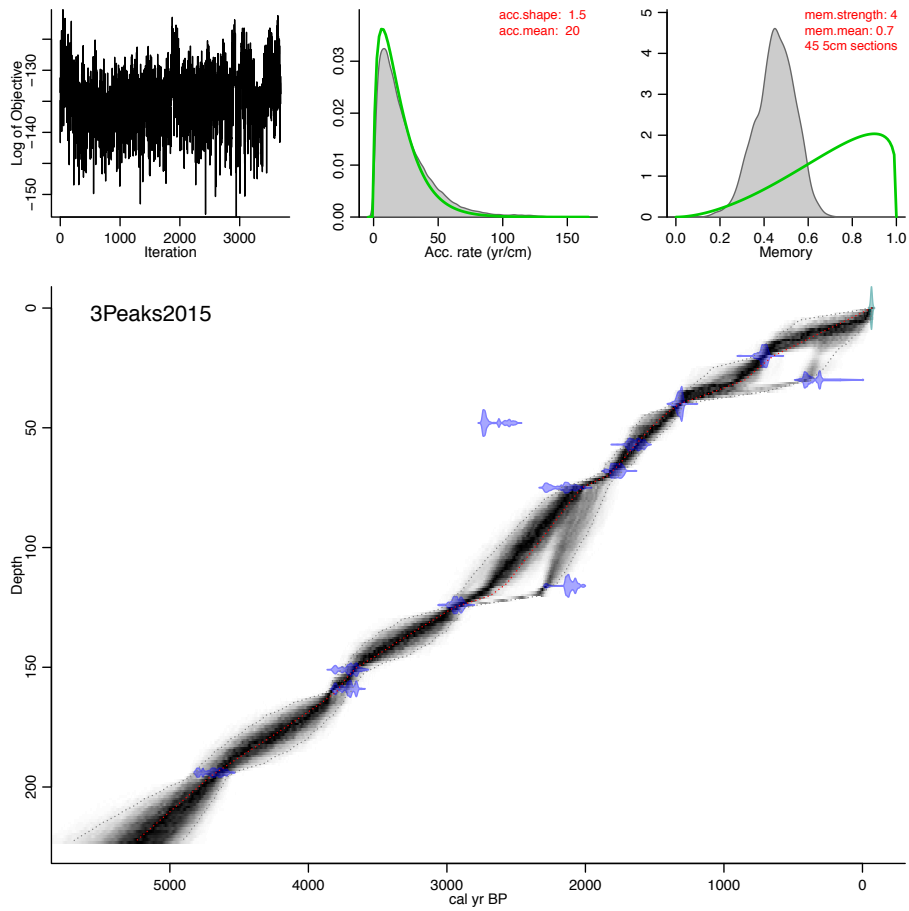


Figure 4. Age-depth model of Three Lakes Peak Lake. The red line shows the interpolated age for each depth of the core, while the grey shading represents the 95% confidence interval. The blue shapes show calibrated radiocarbon dates and the horizontal bars show their error. The date to the left of the model was identified as an outlier and therefore not included in the final model.

Table 1. Radiocarbon Dates for MLM15, 3LP15 and 3LP18. Asterisks indicate outliers that were don't included in final age depth model.

Core	Depth	Lab Reference Number	Material Dated	Uncalibrated Age (C yr BP)	Calibrated Age Range (Cal yr BP)
MLM15	4.5	D-AMS 161672	Bulk Sediment	425 ± 20	491-509
MLM15	10	D-AMS 016919	Bulk Sediment	922 ± 36	761-924
MLM15	27	D-AMS 016922	Bulk Sediment	1000 ± 27	912-956
MLM15	30	D-AMS 016923	Bulk Sediment	*4836 ± 43	5483-5528
MLM15	47	D-AMS 014421	Bulk Sediment	3408 ± 28	3577-3719
MLM15	54	D-AMS 014422	Bulk Sediment	3627 ± 30	3898-3976
MLM15	70	D-AMS 016924	Bulk Sediment	3968 ± 25	4415-4440
MLM15	89	D-AMS 014420	Bulk Sediment	4499 ± 25	5047-5202
MLM15	90	D-AMS 016925	Bulk Sediment	6635 ± 33	7498-7566
3LP15	20	D-AMS 016926	Bulk Sediment	793 ± 32	687-728
3LP15	30	D-AMS 016927	Bulk Sediment	287 ± 23	356-433
3LP15	40	D-AMS 016920	Bulk Sediment	1413 ± 25	1298-1330
3LP15	48	D-AMS 014423	Bulk Sediment	*2562 ± 27	2714-2748
3LP15	57	D-AMS 014424	Bulk Sediment	1726 ± 31	1562-1706
3LP15	75	D-AMS 016921	Bulk Sediment	2153 ± 35	2066-2082
3LP18 A	68	D-AMS 155572	Bulk Sediment	1840 ± 20	1713-1825
3LP18 A	116	D-AMS 155573	Bulk Sediment	2130 ± 50	2038-2154
3LP18 B	124	D-AMS 155574	Bulk Sediment	2830 ± 20	2871-2991
3LP18 B	151	D-AMS 155575	Bulk Sediment	3440 ± 30	3640-3721
3LP18 C	169	D-AMS 155576	Bulk Sediment	3450 ± 20	3640-3730
3LP18 C	204	D-AMS 155577	Bulk Sediment	4140 ± 20	4575-4729

Pollen and Charcoal Data

Pollen percentage data from 3LP Lake and Mud Lake were divided into four pollen zones respectively based on visual inspection of pollen assemblages (Fig. 5 & 6).

Mud Lake (MLM)

Zone MLM-1: >5400 – 4100 cal yr BP (94 – 56 cm depth). In Zone MLM-1 (Fig. 5), *Pseudostuga/Larix* was abundant, reaching concentrations of up to 16% around 5100 cal yr BP, then declining towards the top of the zone and *Alnus* percentages reach their

highest levels. Shrubs, herbs, and grasses (i.e. *Artemisia*, *Rosaceae*, *Amaranthaceae*) had high concentrations at the bottom of this zone and decreased over time. The ratio of arboreal to non-arboreal pollen (AP:NAP) reflects this trend. *Artemisia* had multiple peaks at values close to 10% in this zone. *Poaceae* percentages were about 3-5%, and decreased to approximately 2% at the top of the zone. *Quercus* and *Amaranthaceae* pollen percentages approached 5% then decrease to 1% or less by the top of the zone. Percentage of *Pinus* were low at the start of Zone MLM-1 compared to the rest of the record, and steadily increased towards the upper bounds of the zone. Total PAR ranged from the record's minimum value at 1002 to 4010 grains $\text{cm}^{-2} \text{yr}^{-1}$. CHAR and BCHAR were elevated until around 4100 cal yr BP. Mean fire frequency was 3-4 fires 1000 yrs⁻¹ during this period.

Zone MLM-2: 4100 to 3250 cal yr BP (56 - 43 cm depth). In Zone MLM-2 featured a modest decrease in *Pinus*, coupled with increased *Abies* pollen to almost 15% and *Picea* increased to 8.5%. The percent of Haploxylon-type *Pinus* grains increased to 16% around 3770 cal yr BP. During this period AP:NAP ratios were stable, and total PAR rose from the bottom to top of the zone reaching 5076 grains $\text{cm}^{-2} \text{yr}^{-1}$. Both BCHAR and CHAR decreased with only 1 significant fire peak.

Zone MLM-3: 3250 to 1400 cal yr BP (43 – 26 cm depth). In Zone 3 *Picea* and *Abies* pollen decreased to values of just under 1% and 1.6 % respectively. Haploxylon-type *Pinus* gradually increased to 21% by 1680 cal yr BP, while Diploxylon-type *Pinus* ranged between 13-20%. Shrubs, herbs and grasses saw slight increases in abundance as

well (i.e. *Artemisia*, *Rosaceae*, *Amaranthaceae*). During this time, the AP:NAP ratio was also fairly constant, while total PAR was low at 1590 grains cm⁻² yr⁻¹ to 3966 grains cm⁻² yr⁻¹. Throughout this zone CHAR and BCHAR remained relatively low, though the record reflects multiple significant fire episodes and a mean fire frequency of 4 fires 1000 yrs⁻¹.

Zone MLM-4: 1400 to 0 cal yr BP (26 to 0 cm depth). From 1400 to 1000 cal yr BP, Zone MLM-4 showed an increase of *Picea* and *Abies* pollen to their maximum values at approximately 11% and 16% respectively. After this initial increase, percentages of these taxa declined towards 2-5%. In this same window of time, there was a notable decrease in *Pinus* pollen and total PAR reached its maximum value for this record at 7536 grains cm⁻² yr⁻¹. By approximately 1250 cal yr BP total *Pinus* percentages were at their lowest levels c. 41%. *Alnus* also recorded their lowest percentages in this zone. CHAR and BCHAR levels were elevated, and the maximum peak of CHAR occurred at the beginning of this zone.

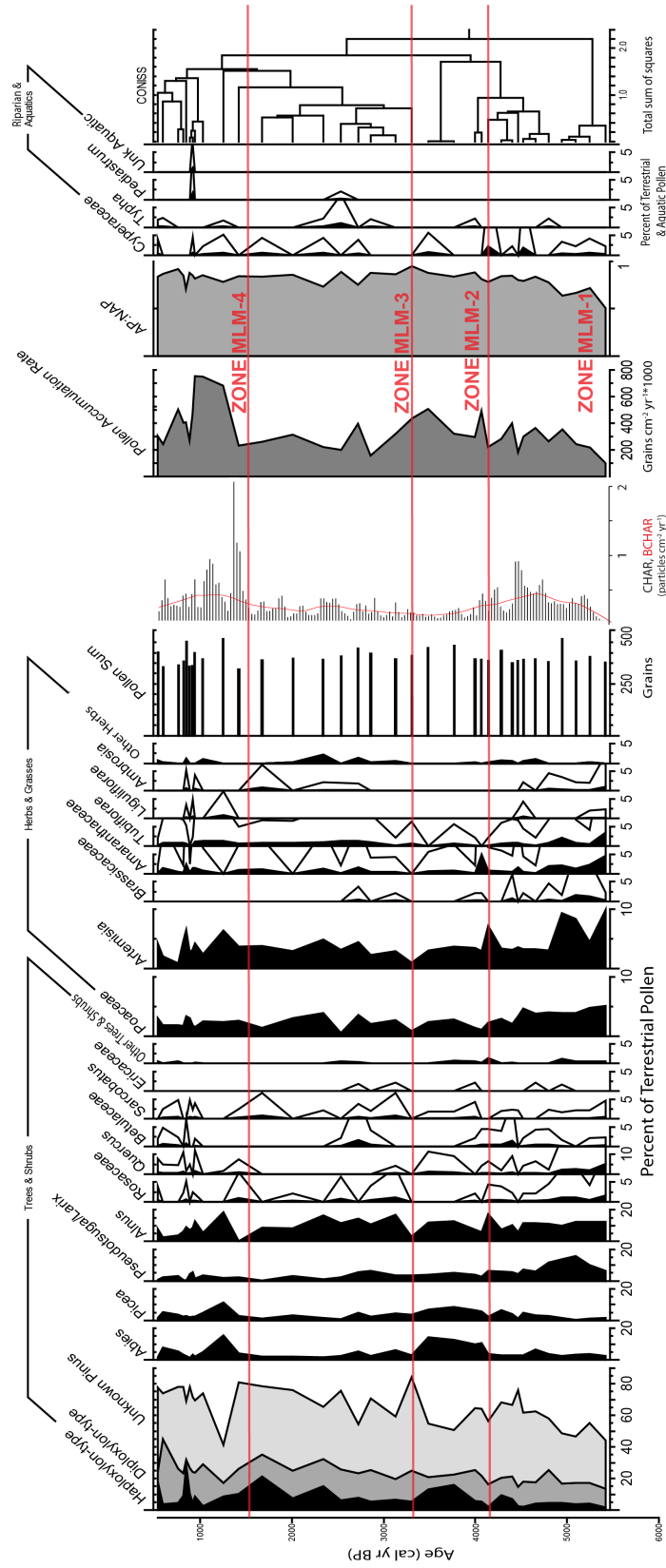


Figure 5. Pollen percentage diagram showing selected taxa from Mud Lake, Montana. Terrestrial pollen percentages based on terrestrial pollen sums, and aquatic pollen percentages are of aquatic and terrestrial pollen sums. Outlines represent 5x exaggeration. X axes represent percent each taxon contributes to the total pollen sum of terrestrial taxa. AP:NAP represents the ratio of arboreal pollen to non-arboreal pollen indicating forest density.

Three Lakes Peak Lake

Zone 3LP-1: 4600 to 3150 cal yr BP (205 – 132 cm depth). In Zone 3LP-1 (Fig X), *Alnus* reached its maximum of the record at 40.5%, and values between 14-33% for the remainder of the zone, with a decreasing trend after 4200 cal yr BP. *Pinus* percentages were low, with a minimum value of approximately 41% at 4241 cal yr BP, that increased higher in the zone. At 4138 cal yr BP, total PAR spiked to 5002 grains cm⁻² yr⁻¹ and was stable throughout the rest of this period. AP:NAP did not vary significantly throughout this zone. Fire activity was modest, as reflected by intermediate levels of BCHAR and CHAR, and a fire frequency of approximately 1 fire 1000 yrs⁻¹.

Zone 3LP-2: 3150 to 2300 cal yr BP (132 – 95 cm depth). Throughout this zone, Haploxylon-type, Diploxylon-type and undifferentiated *Pinus* along with *Picea*, *Abies*, *Psuedostuga*, and *Alnus* maintained stable percentages. Poaceae percentages decreased from values of around 4%, and PAR had 1800-3000 grains cm⁻² yr⁻¹. BCHAR and CHAR reached minimum values in this zone while fire frequency was 1 fire 1000 yrs⁻¹.

Zone 3LP-3 2300 to 1550 cal yr BP (95 – 52 cm depth). Zone 3LP-3 had high percentages of *Alnus* (28%), that decreased to 10% at the top of the zone. This period shows sharp fluctuations of percentages of conifers, herbs and grasses as well as in total PAR. BCHAR and CHAR reached their maximum values during this time indicating high fire activity with a mean fire frequency of approximately 4 fire events 1000 yr⁻¹.

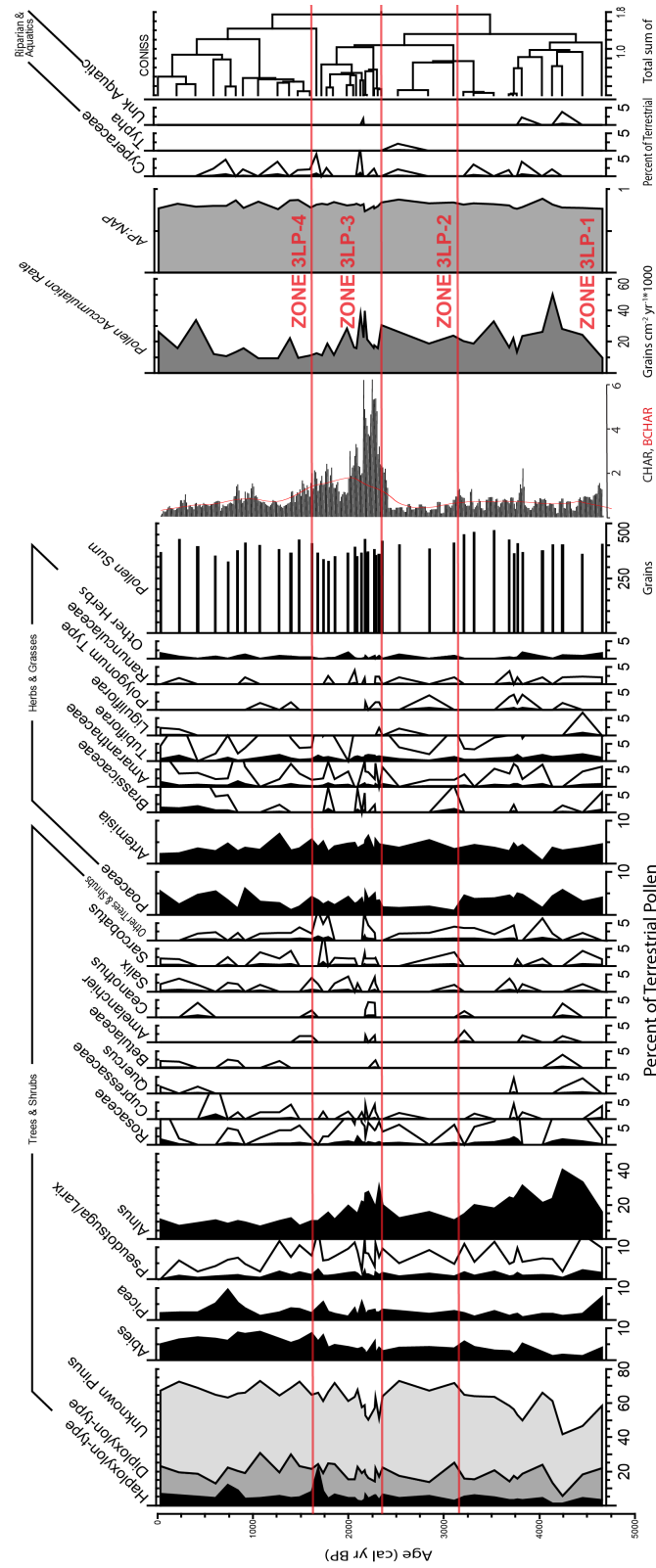


Figure 6. Pollen percentage diagram showing selected taxa from Three Lakes Peak Lake, Montana. Terrestrial pollen percentages based on terrestrial pollen sums, and aquatic pollen percentages are of aquatic and terrestrial pollen sums. Outlines represent 5x exaggeration. X axes represent percent each taxon contributes to the total pollen sum of terrestrial taxa. AP:NAP represents the ratio of arboreal pollen to non-arboreal pollen indicating forest density.

Zone 3LP-4: 1550 to 0 cal yr BP (52 to 0 cm depth). *Abies* and *Picea* reached their maximum percentages of 9% after 1000 cal yr BP at 3LP Lake, while *Pinus* values were high in the range of 64-74%. *Alnus* levels remain stable and relatively low. BCHAR and CHAR values decrease from Zone 3LP-3 and follow this downward trend to the top of the record. Mean fire frequency decreased to c. 2 fires 1000 yrs⁻¹ in this zone.

DISCUSSION

To better understand local versus regional changes in vegetation and fire activity, these records are compared with the only two other pollen records in the Flathead region, Foy Lake (Power et al., 2011) and Twin Lakes (Alt et al., 2018). Foy Lake is a low-elevation site (c. 1006 masl) representing a steppe-forest ecosystem in the Flathead Valley. Twin Lakes is a mid-elevation (c. 1236 masl) mixed conifer forest in the southern Mission Mountains. These sites were chosen to see how nearby sites at different elevations and forest zones changed overtime. The records are also compared to four other high-elevation sites from the broader region of the northern Rocky Mountains to better understand regional trends in subalpine forests.

Three of these regional high-elevation sites, Baker, Hoodoo, and Burnt Knob Lakes, are in the Bitterroot mountains near the Idaho-Montana border. All three lakes currently are surrounded by subalpine forests consisting of *Abies bifolia*, *Pinus albicaulis*, *P. contorta*, and *Picea engelmannii*. Fairy Lake, just southeast of these sites, sits in the Bridger mountains, surrounded by a diverse mixed-conifer/subalpine forest. Additional information about all comparison sites is listed in Table 2.

Table 2. Regional comparison site information.

Site Name	Latitude/Longitude	Elevation (m)	JJA ppt (cm)	DJF ppt (cm)	Present day Vegetation	Reference
Foy Lake	48.164 N/114.350 W	1006	13.5	10	<i>P. ponderosa</i> , <i>Pseudotsuga</i> , <i>L. occidentalis</i> , <i>Picea</i>	Power et al., 2011
Twin Lake	47.241 N/113.911 W	1236	14	21	<i>Pseudotsuga</i> , <i>P. ponderosa</i> , <i>A. grandis</i> , <i>L. occidentalis</i>	Alt et al., 2018
Mud Lake	47.618 N/113.997W	1765	35.8	23.1	<i>A. lasiocarpa</i> , <i>P. engelmannii</i> , <i>Pseudotsuga</i> , <i>P. albicaulis</i>	This study
Hoodoo Lake	46.320 N/114.652 W	1770	20	67	<i>P. contorta</i> , <i>Picea</i>	Brunelle et al., 2005
Burnt Knob Lake	45.700 N/114.990 W	2250	18	31	<i>A. bifolia</i> , <i>P. albicaulis</i> , <i>P. contorta</i>	Brunelle et al., 2005
Baker Lake	45.892 N/114.262 W	2300	23	66.5	<i>A. bifolia</i> , <i>P. albicaulis</i> , <i>L. lyallii</i>	Brunelle et al., 2005
Fairy Lake	45.904 N/110.958 W	2308	33.3	26.7	<i>Abies</i> , <i>Picea</i> , <i>P. contorta</i> , <i>Pseudotsuga</i> , <i>J. communis</i> , <i>P. albicaulis</i>	Benes et al. 2019
Three Lakes Peak Lake	47.255 N/ 114.559	2375	18.3	34.5	<i>A. lasiocarpa</i> , <i>P. engelmannii</i> , <i>P. albicaulis</i>	This study

Mid-Holocene

By ca. 5000 cal yr BP, mid to high elevations of the NRM are thought to have been dominated by closed forests (Alt et al. 2018; Brunelle et al. 2005). The pollen data at MLM shows that the entire span of the record is dominated by *Pinus*, *Abies*, *Picea*. From 5400 to 4100 cal yr BP, Mud Lake reflects a slightly drier mixed conifer forest with

high percentages of *Pseudotsuga* (15%), high concentration of *Artemisia*, *Poaceae*, lower AP:NAP ratio and frequent burning. Although *Pseudotsuga* and *Larix* pollen is indistinguishable, the pollen record indicates it is likely representing *Pseudotsuga* because this species is currently present at the site.

High percentages of *Alnus* likely represent a more open landscape and potentially fire disturbances that promote the expansion of *Alnus* following the post-fire decrease of dense stands *Abies* and *Picea*. Haploxylon-type *Pinus* increased between 4000 and 3000 cal yr BP at Mud Lake. Modern forest appears to have been established around 3500 cal yr BP indicated by the significant drop in *Pseudotsuga* and dry open-forest taxa including *Artemisia* and *Poaceae*.

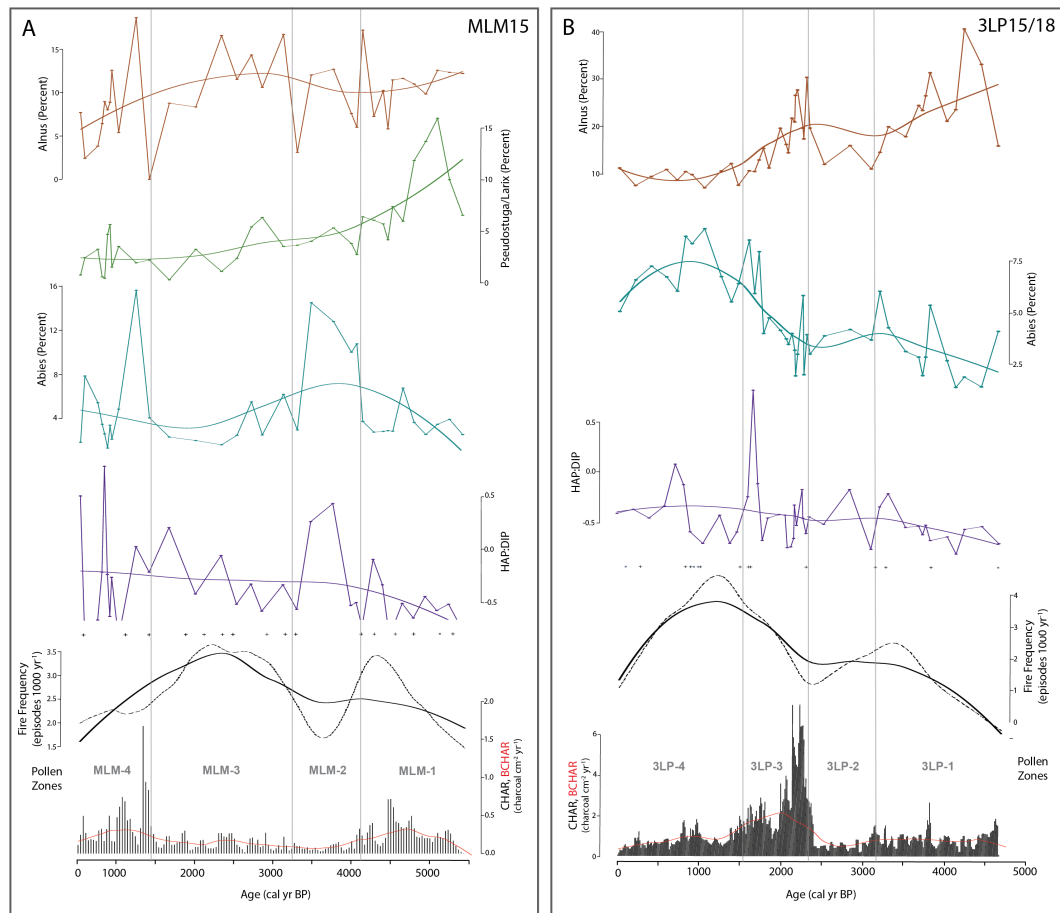


Figure 7. A) Pollen percentage data of selected taxa and charcoal data from Mud Lake. B) Pollen percentage data from selected taxa and charcoal data from Three Lakes Peak Lake. B excludes *Pseudotsuga/Larix* as it wasn't a significant portion of the pollen sum. HAP:DIP refers to the ratio of Haploxyton-type *Pinus* to Diploxyton-type *Pinus*. Showcases more open lake margins dominated by *Alnus* during the mid-Holocene, increasing subalpine taxa (*Abies* & Haploxyton-type *Pinus*), and peak fire frequency and CHAR in the late-Holocene.

Consistent with regional trends, increasing *Pinus* pollen at 3LP Lake seems to indicate forest infill, as conditions became cooler and wetter following the mid-Holocene (Routsen et al., 2019). The record begins with abundant *Alnus*, an early colonizer following disturbances such as fire, avalanche, and mass wasting (Gerloff et al., 1995). As a riparian species, high percentages could also indicate wetter conditions (Brunelle et

al., 2005). These initial high percentages of *Alnus* could also suggest frequent disturbance such as fire, though avalanches could also promote increases in *Alnus* as there is a large avalanche slide path running into the lake. A relatively low HAP:DIP ratio (Fig. 7b) indicates that five needle pines were not as abundant at the start of the record as they were in the late-Holocene when fire activity was higher. This is congruent with expectations for the relationship between five needle pines and fire.

During the onset of the late Holocene c. 3000 cal yr BP, Mud Lake saw an increase in *Abies* and *Picea* corresponding with higher Haploxylon-type *Pinus*, indicating a continued shift from drier mixed conifer forest towards subalpine forest. During this period low CHAR but higher fire frequency may suggest more frequent, small fires promoting a more heterogenous landscape and encouraging the expansion of Haploxylon-type *Pinus*. Around 3000 cal yr BP, modern forest appears to have established at 3LP, shown in the record by notable decreases in both *Alnus* and *Poaceae*, and the start of a gradual increase in major subalpine forest taxa *Picea* and *Abies* that continued through the late-Holocene. Decreases followed by increases in Haploxylon-type *Pinus*, *Pseudotsuga* and *Alnus* c. 2200, 1600, and 300 cal yr BP suggest fires may have created conditions favorable (e.g., decreased competition with *Abies*, *Picea*) for increases in the abundance of taxa well-adapted to establish in post-fire environments. These post-fire increases in pollen percentages for these taxa are particularly evident in the pollen diagram for the alternative age-depth chronology (Appendix A Fig. 1)

Late-Holocene

At Mud Lake, a notable decrease in *Picea* and *Abies* pollen occurred at ca. 2500 cal yr BP coincident with a substantial increase in Haploxylon-type *Pinus* pollen. Although CHAR levels remain low through this subtle pollen transition, fire episodes were more frequent, suggesting these fires potentially promoted the expansion of five-needle pine parklands over previous spruce-fir forests. Around 2300 cal yr BP fire activity increased significantly at 3LP. The 3LP pollen record around this time shows sharp fluctuations in percentage of *Pinus*, *Abies*, *Picea*, *Alnus*, *Poaceae*, and *Artemisia* which may be linked to fire episodes. *Alnus* becomes more prevalent in the record over this time as well, further indicating that the vegetation was likely responding to fire or another disturbance. Haploxylon-type *Pinus* reaches peak levels c. 2300 when the highest levels of fire activity are recorded suggesting Haploxylon-type *Pinus* expanded following fire.

Over the last 1400 years at Mud Lake, fire frequency decreased from 4 to 2 episodes per 1000 years while BCHAR and CHAR hit record peaks. 3LP Lake fire activity remained moderate over this period with decreasing fire frequency from 4 to 1 episode per 1000 years.

Abies and *Picea* show relative abundance over the last 1500 cal yr BP at both sites, indicating moist subalpine forests much like present-day forests. As conditions became wetter, stand-replacing fires may have become more common with increasing

climate variability providing opportunity for occasional drought driven fires (Alt et al., 2018; Benes et al., 2019; Carter et al., 2017).

One of the most significant fire peaks of the record occurs around 900 cal yr bP where Mud and 3LP share peaks in CHAR. The Medieval Climate Anomaly (MCA), a period of anomalous warming c. 1200-700 cal yr BP, (Mann et al., 2009)) may have facilitated large fire events. Following the MCA in both pollen records, there is notable increases in Haploxylon-type *Pinus*, suggesting a relationship between five-needle pines and fire activity in these high elevation sites. Fire seems to promote the abundance of five-needle pines at high elevation sites throughout the mid- to late-Holocene, possibly because fires reduced competition allowing for increased establishment and expansion of this taxa. Mud Lake, *Alnus* peaks again following this fire peak, indicating the fire activity may have promoted this post-disturbance riparian species.

Flathead Region Elevational Comparison

Dominant forest types shifted in elevation in response to climatic variability from the mid-Holocene until present day (Fig. 8). At Foy Lake, forest cover increased between 6000 and 4000 cal yr BP, expanding dry open forests into lower elevations than present day, suggesting lower tree line moved downslope with mid-Holocene warming (Power et al., 2011). At Twin Lake, forests closed by 4800 cal yr BP, and were starting to show decreasing dry forest taxa like *Pseudotsuga*, and increased mesic taxa like *Picea* (Alt et al. 2018). Mud Lake at this time also shows a drier, *Pseudotsuga* rich forest. Similarly, the subalpine forest in the 3LP watershed was likely more open and drier during the mid-

Holocene. Warmer conditions likely facilitated higher subalpine treeline position during the mid-Holocene.

The Foy lake records show slight expansion of mesophytic forest at the low-elevation sites in the late-Holocene, coincident with increases in mesic taxa in the Twin, Mud, and 3LP Lake records during that period. Present day forest-steppe establishment occurred at Foy Lake just after 1500 cal yr BP shown by decreases in *Abies* and *Picea*, while *Pseudotsuga*, *Pinus*, *Poaceae* and *Artemisia* became more prevalent (Power et al., 2011). Modern forest established at Twin Lake by 2800 cal yr BP shown by a similar increase in open-forest understory taxa like *Poaceae*, *Alnus* and *Artemisia*. The higher elevation sites of Mud and 3LP had already established modern forests by between 3500-3000 cal yr BP, though the trend towards cooler, moister, denser subalpine forests continued through the late-Holocene. Upper tree line lowered to modern level in the late-Holocene, and the subalpine vegetation zone lower boundary dropped in elevation, including Mud Lake.

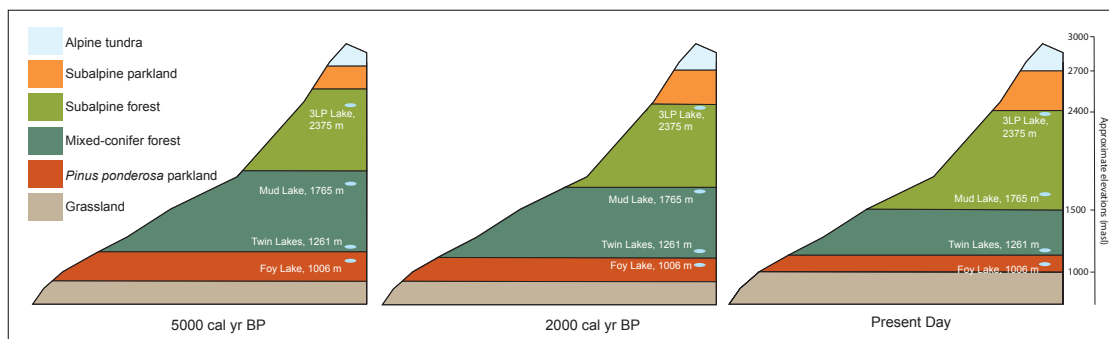


Figure 8. Forest zones by elevation from mid-Holocene (ca. 5000 cal yr BP), late-Holocene (ca. 2000 cal yr BP), to present day based upon records from the Flathead region of Montana (Alt et al 2018, Power et al., 2011). Shows expansion of subalpine forests approaching present day (adapted from Alt et al., 2018 Fig. 2).

High-Elevation Regional Comparison

Approaching the mid-Holocene, a long-term trend towards decreasing summer insolation led to cooler and moister conditions throughout the region (Power et al., 2011). Closed forests began establishing by 6000-5000 cal yr BP (Brunelle et al., 2005, Benes et al., 2019). Regional pollen records from sites in northwestern Montana including Burnt Knob, Hoodoo, Baker, and 3LP Lakes showed vegetation compositions indicative of more dry mixed conifer forests, trending towards mesic subalpine forest and/or parkland as modern forests established (Fig. 9, Brunelle et al., 2005). The two more eastern sites, Mud and Fairy Lakes, had dry, open *Pseudotsuga* parkland compositions during the mid-holocene, shifting towards relatively diverse mesic mixed conifer/subalpine forests approaching present day (Benes et al., 2009). Baker Lake, Burnt Knob, and Hoodoo Lake's pollen records all show *Alnus* as a significant component of the forest composition during the mid-Holocene around 5000 cal yr BP as is seen in the 3LP and Mud Lake records further supporting the idea that forests were more open during this period.

Modern forest establishment occurred at all sites between 4000-2000 cal yr BP (Benes et al., 2019; Brunelle et al., 2005). This shift occurred latest at the lowest elevation site, Hoodoo Lake, and the farthest southeast site, Fairy Lake. Following modern forest establishment, all high-elevation sites in this study trended towards cooler, moister vegetation compositions than previous. Northwestern sites shifted towards

subalpine forest and/or parkland, while eastern forests showed slightly more diverse mixed-conifer taxa and high subalpine forest dominants like *Abies* and *Picea*.

As fuel loads increased from infill of conifers, climate variability increased drought-driven fire activity as these fuel rich landscapes became incredibly flammable upon drying (Huerta et al. 2008). Regional CHAR reached its Holocene maximum at high elevations around 5000 cal yr BP, and low elevations around 2000 cal yr BP (Alt et al., 2018). High elevation sites including Baker Lake, and Foy Lake show clear peaks in fire frequency near 5000 cal yr BP and 2000 cal yr BP (Brunelle et al., 2005; Power et al., 2011). The Mud Lake charcoal record shows elevated BCHAR and CHAR around 5000-4200 cal yr BP, while the 3LP record is synchronous with the latter trend peaking around 2000 cal yr BP. This indicates the influence of broad-scale regional and local controls on fire activity at these sites. One possible explanation to this is the great variation in topography at high elevations in the mountains creating microclimates, promoting heterogeneity.

Over the last 2000 years, NRM western mesic mixed and subalpine conifer forests expanded as climate continued to trend toward cooler summers and higher effective moisture (Shuman et al., 2016; Power et al., 2011; Minckley et al., 2008; Mensing et al., 2011). Taxa like *Picea* and *Abies* became more abundant at Baker, Burnt Knob, and Fairy Lake (Brunelle et al., 2005, Benes et al., 2019). This trend towards increasing subalpine taxa is also visible in the 3LP record, and Mud Lake record to a lesser extent, likely due its position at lower elevation.

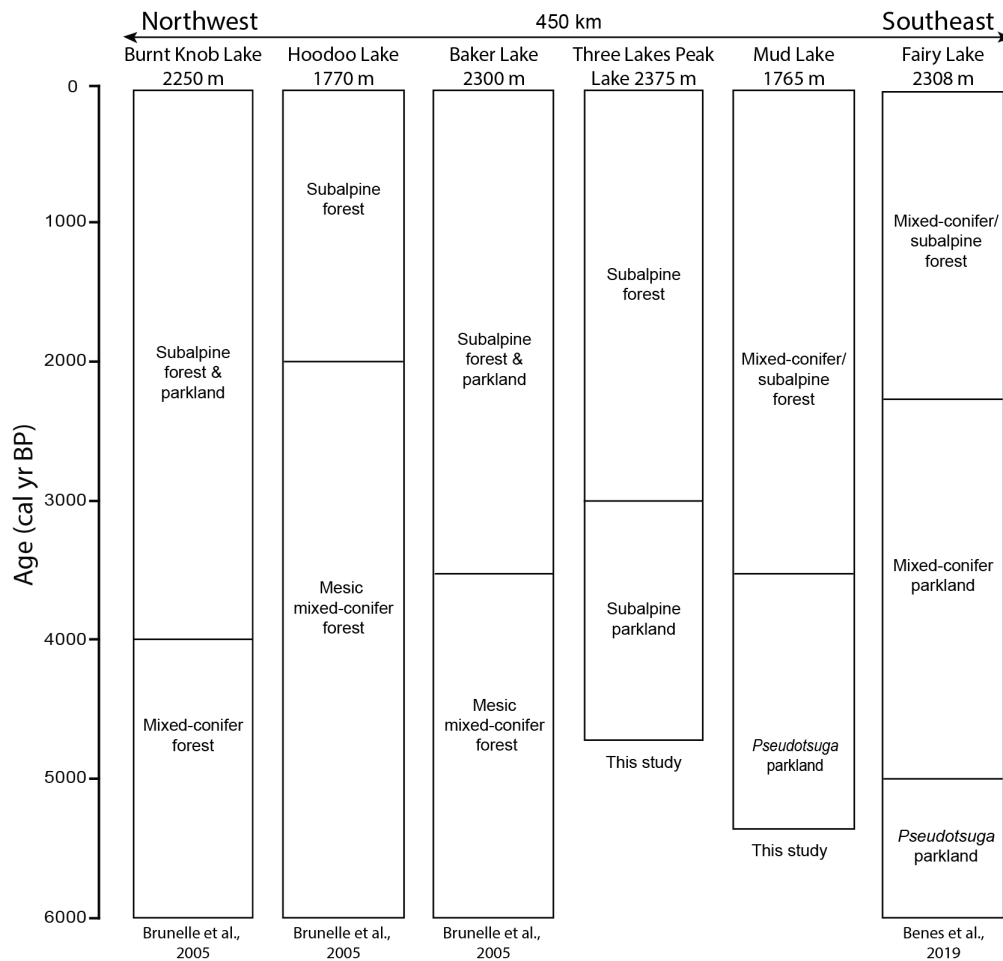


Figure 9. Regional comparison with high elevation sites from the Northern Rocky Mountains from northwest to southeast. Vegetation changes are marked by horizontal lines in each column, the uppermost line representing the transition to modern forest composition, occurring at all sites between 4000 and 2000 cal yr BP.

Over the last two millennia mid to high elevation NRM sites show increasing fire activity. Brunelle et al. (2005) found greater fire activity as records approached present day at Baker Lake. This is potentially due to high arboreal fuel loads from subalpine forest development promoting more stand replacing fires. The charcoal records from 3LP and MLM15 show maximum CHAR values (large, potentially high-severity fire events)

and decreasing fire frequency during the last 2500 years. Fire frequency at Burnt Knob Lake increased during this period, as charcoal accumulation rate decreased, suggesting more frequent smaller fires, which contrasts from regional trends. Over this time five-needle pine pollen was significant in the Burnt Knob Pollen record, in alignment with trends in the abundance of five-needle pine seen in the 3LP and Mud Lake records.

Paleoenvironmental records across the Western US do not show a consistent signal of warming during the MCA, though regional charcoal records from some high elevation sites show a signal of increased fire activity in this period (Carter et al., 2017). In this study, charcoal accumulation rates reached their record maximum from 1000-800 cal yr BP at Mud Lake, while 3LP CHAR shows a smaller CHAR peak from 1027-715 cal yr BP. One possible explanation of these peaks is that these forests were responding to enhanced dryness or warming during the MCA. Burnt Knob lake shows increased fire frequency during the MCA while Baker and Hoodoo Lakes both show increased fire activity just prior to the MCA at ca. 2000 cal yr BP. This is also synchronous with the timing of the 3LP record peak fire activity, suggesting that there may be a consistent MCA aridity driven trend in fire activity across high elevation sites in the NRM.

CONCLUSIONS

The paleoenvironmental reconstruction at Mud Lake and Three Lakes Peak highlight the persistence of western subalpine and mixed-conifer forests in the NRM over the last five millennia. It is evident that closed forests were established prior to 5400 cal yr BP at Mud Lake and 4600 cal yr BP at 3LP Lake due to the abundance of *Pinus* throughout both records along with high abundances of *Picea*, *Abies*, and *Psuedostuga*. The records capture minor transitions in vegetation as climate shifted from early to mid-Holocene warmth and aridity marked by more open, dry forests into the cooler and wetter late Holocene and development of subalpine forests. The presence of *Alnus* throughout the records coincided with periods of increased disturbance and more open forests in these watersheds. This general pattern was evident at low, middle, and high elevation sites in the Flathead region. Modern forests were established along with other high elevation sites in the region from 3500-3000 cal yr BP. Charcoal records at Mud, 3LP and other high elevation lake sites around the region showed increased fire activity around or just prior to the MCA.

Whitebark pine, shown in pollen records as a contributor to Haploxylon-type *Pinus*, is adapted to a mixed-severity fire regime, that is highly critical to the persistence of the species on the landscape. Infrequent, stand replacing fires create openings for seeding by Clark's Nutcrackers to assist reproduction, cycle essential nutrients and biomass in the ecosystem, and prevents whitebark pine from being replaced by late-successional shade tolerant species like spruce and fir (Iglesias et al., 2014). Whitebark

regenerates very well following fire, and this relationship is evident in the Mud and 3LP pollen records.

The most notable shift in Haploxyton- type *Pinus* at Mud Lake and 3LP during the late Holocene was coincident with increased fire activity in the MCA, reinforcing the importance of fire for the persistence of five needle pines like whitebark pine (Hansen et al., 2016). Advances in pollen aDNA analysis might aid in identifying ecologically significant species like whitebark pine in sediments, providing greater confidence in pollen record interpretation, in addition to improving understanding of how these stands respond to climate-driven shifts in disturbance regimes.

In recent decades, mid- to high-elevation forests in the NRM have experienced significant increases in fire as a result of climatic shifts such as warmer springs, drier summers, and reduced winter snowpack (Pederson et al., 2010; Montana Climate Assessment, 2017). These forests, generally adapted to high-severity fire regimes, were likely only minimally impacted by 20th century fire exclusion. With fire return intervals of 100 yr or more, much longer than the roughly 50 yr period of intensive suppression, it is unlikely that subalpine forests were affected, suggesting the large fires of the last several centuries in the region are not anomalous (Carter et al., 2017). Projected decreases in winter precipitation and warming temperatures in the future however, could foster unprecedented conditions and complex interactions with vegetation and fire to produce novel disturbance regimes in these sensitive subalpine forests (Carter et al., 2017). Potential future anomalously warm or dry conditions, like those seen in the MCA, may increase forest flammability and push subalpine forests over ecological thresholds

beyond which they are unable to recover. If stand replacing fires become more frequent, subalpine forests may become unable to regenerate adequately, causing a shift to open forests of xeric species such as Douglas fir, larch or ponderosa pine or even non-forest shrublands or grasslands. Turner et al., (2019) found that complicating effects and feedbacks like the effects of competition on seedling survival or changing albedo on soil moisture are likely to add complexity to forests response to increased fire.

Global temperatures had already risen an average of 0.74°C since 1900 by 2006 and a minimum global temperature rise of 2°C is predicted by 2100 (Pederson et al., 2010; Carter et al., 2017). In comparison, by 2006 Western Montana's average annual temperature had risen 1.3°C since 1900, and is expected to rise $1.7 - 3.7^{\circ}\text{C}$ above mid-20th century averages by 2050 (Pederson et al., 2010; Montana Climate Assessment, 2017). Not only are NRM forests seeing some of the most significant temperature anomalies, they are also highly vulnerable to the consequences of these climatic shifts due to projected decreases in annual snowpack (Pederson et al., 2010). Since the majority of the moisture subalpine systems rely on arrives as snow during the winter months, decreased snowpack could drastically reduce effective moisture in these forests during the summer. It is likely that with hotter, drier conditions in coming decades, we will see increased fire events in these fuel rich forests.

Ecologically significant taxa such as whitebark pine are of special concern, and the impacts of shifting conditions are uncertain due to their vulnerability to warm and dry conditions, but generally higher tolerance to drought and fire than other conifers like spruce and fir (Hansen et al., 2016). Further adding complexity, climate change is likely

to impact insect and pathogenic disturbances. Unlike fire, these disturbances hinder whitebark pine's ability to survive and reproduce on the landscape, and thus could contribute to their continued population decline in coming decades. Additionally, tree mortality from these outbreaks can greatly increase forest flammability, and thus may amplify the effects of climate change in these systems.

Projections suggest fire activity in subalpine forests will increase into the future, with possible short-intervals between the occurrence of fires. At large scales, it is unlikely that forest management can modify fuel conditions to prevent increases in fire activity in the fuel-rich and relatively inaccessible subalpine forests of northwestern Montana. Management efforts aimed at minimizing fire risk and hazard to communities might be best targeted in the mid and low elevation forests below where fuel treatments might prevent the spread of high-severity fires. Management of the forests near the wildland-urban interface could help prevent fires initiating in the subalpine from threatening residences and cultural resources in the valleys and foothills. Despite this uncertainty, land managers should expect fire in subalpine forests to increase into the future due to projected warming and reduced snowpack. Managing fuels in lower elevation forests at the wildland-urban interface is likely an approach that can best protect communities in the face of increasing fire activity at higher elevations.

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APPENDICES

APPENDIX A

ALTERNATIVE CHRONOLOGY POLLEN DIAGRAM

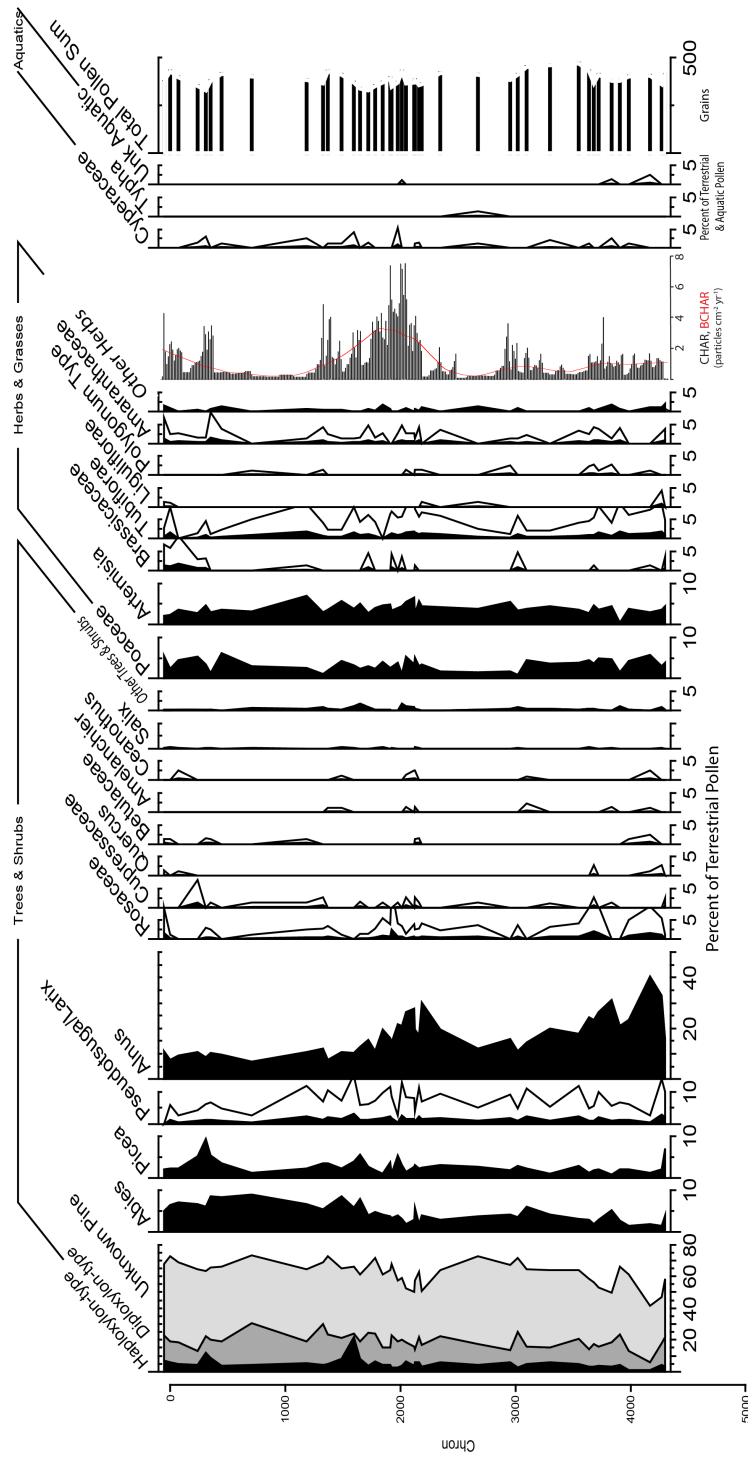


Figure 1. Pollen percentage diagram showing selected taxa and CHAR data from Three Lakes Peak Lake, Montana utilizing an alternative age-depth chronology. Terrestrial pollen percentages based on terrestrial pollen sums, and aquatic pollen percentages are of aquatic and terrestrial pollen sums. Outlines represent 5x exaggeration. X axes represent percent each taxon contributes to the total pollen sum of terrestrial taxa. AP:NAP represents the ratio of arboreal pollen to non-arboreal pollen indicating forest density.

APPENDIX B

RAW CHARCOAL COUNTS

MLM15 – Mud Lake 2015 Core

Age (cal yr BP)	Sediment Depth (cm)	Charcoal Count (# particles >125 μ)	Sediment Volume (cm³)
-65.2	0.5	27	2
-4.1	1	121	2
57	1.5	42	2
118	2	46	2
178.8	2.5	40	2
239.7	3	84	2
300.6	3.5	40	2
361.5	4	121	2
422.5	4.5	22	2
483.4	5	116	2
544.3	5.5	69	2
571.8	6	85	2
599.3	6.5	85	2
626.8	7	53	2
654.3	7.5	44	2
682	8	53	2
709.7	8.5	38	2
737.3	9	16	2
765	9.5	32	2
792.5	10	6	2
835.8	11.5	9	2
843.6	12	14	2
851.3	12.5	8	2
858.9	13	49	2
866.4	13.5	61	2
873.9	14	68	2
881.5	14.5	35	2
888.9	15	39	2
896.5	15.5	38	2
904.3	16	25	2
912.1	16.5	38	2
919.8	17	23	2
927.8	17.5	22	2
935.6	18	45	2
943.4	18.5	23	2
951.1	19	18	2

958.9	19.5	15	2
966.8	20	34	2
1030.1	21.5	27	2
1058.3	22	12	2
1086.5	22.5	9	2
1114.4	23	5	2
1142.6	23.5	14	2
1170.7	24	13	2
1198.7	24.5	27	2
1226.5	25	30	2
1253.9	25.5	38	2
1337.9	26	49	2
1422.4	26.5	101	2
1506.8	27	14	2
1591.2	27.5	29	2
1676.2	28	60	2
1760.1	28.5	23	2
1844.9	29	22	2
1929.1	29.5	90	2
2195.3	31.5	21	2
2244.2	32	14	2
2292.8	32.5	3	2
2341.7	33	22	2
2390.8	33.5	49	2
2439.5	34	22	2
2489	34.5	36	2
2538.2	35	5	2
2587.4	35.5	52	2
2632.1	36	20	2
2677.7	36.5	10	2
2723.5	37	6	2
2769.2	37.5	22	2
2815.3	38	9	2
2860.9	38.5	43	2
2907.1	39	7	2
2952.8	39.5	8	2
2998.3	40	25	2
3043.8	40.5	17	2
3087.7	41	17	2

3131.8	41.5	7	2
3175.5	42	16	2
3219	42.5	8	2
3263.7	43	9	2
3307.9	43.5	14	2
3352.3	44	5	2
3396.8	44.5	5	2
3441.4	45	11	2
3485.6	45.5	12	2
3526.2	46	18	2
3566.6	46.5	20	2
3607.1	47	21	2
3647.4	47.5	26	2
3687.8	48	3	2
3728.3	48.5	10	2
3768.9	49	7	2
3810.2	49.5	29	2
3895.4	50	9	2
3930.4	51	19	2
3965.3	52	23	2
4000.4	53	18	2
4035.4	54	6	2
4070.5	55	18	2
4106.4	56	24	2
4142.2	57	35	2
4178	58	13	2
4213.6	59	10	2
4249.3	60	6	2
4279	61	7	2
4308.7	62	9	2
4338.2	63	13	2
4368	64	43	2
4397.3	65	41	2
4427.7	66	45	2
4459	67	32	2
4490.3	68	24	2
4521.3	69	25	2
4552.6	70	22	2
4620	72	22	2

4653.9	73	26	2
4688	74	33	2
4721.7	75	34	2
4759.9	76	18	2
4798.5	77	16	2
4836.7	78	16	2
4873.9	79	19	2
4911.6	80	11	2
4947.7	81	19	2
4984.2	82	10	2
5020.7	83	12	2
5057.1	84	18	2
5093.7	85	21	2
5130.6	86	12	2
5167.3	87	17	2
5204.2	88	25	2
5240.7	89	21	2
5277.2	90	18	2
5369.1	92	5	2
5414.5	93	2	2
5459.2	94	0	2
5529.9	95.5	0	2

3LP15 – Three Lakes Peak Lake 2015 Core

Age (cal yr BP)	Sediment Depth (cm)	Charcoal Count (# particles >125 μ)	Sediment Volume (cm ³)
-64.4	0	5	2
-45.7	0.5	19	1.5
-27.3	1	21	2
-8.9	1.5	31	2
9.6	2	24	1
28	2.5	38	2
46.4	3	26	1.5
64.9	3.5	28	2
83.5	4	36	2
102.1	4.5	40	2
120.8	5	56	2
138.8	5.5	56	2

156.7	6	43	2
174.6	6.5	82	2
192.6	7	49	2
210.7	7.5	23	2
228.6	8	43	2
246.4	8.5	34	2
264.4	9	33	2
281.8	9.5	25	2
299.6	10	64	2
317.9	10.5	46	2
336.9	11	55	2
355.8	11.5	42	2
374.6	12	62	2
393.4	12.5	55	2
412.5	13	52	2
431.3	13.5	49	2
450.4	14	54	2
469.3	14.5	57	2
488	15	67	2
510.5	15.5	69	2
533.4	16	71	2
555.9	16.5	27	2
578.5	17	54	2
601.3	17.5	47	2
624.4	18	47	2
647.4	18.5	61	2
670.6	19	63	2
694	21	45	2
716.9	21.5	72	2
728.3	22	74	2
739.5	22.5	81	2
750.7	23	51	2
762	23.5	36	2
773.1	24	45	2
784.1	24.5	33	2
795.2	25	30	2
806.2	25.5	43	2
817.1	26	64	2
828.2	26.5	37	2

839.3	27	53	2
850.9	27.5	62	2
862.2	28	40	2
873.7	28.5	46	2
884.9	29	70	2
896.2	31	91	2
907.6	31.5	70	2
918.9	32	65	2
930.3	32.5	61	2
941.6	33	65	2
961.1	33.5	54	2
980.6	34	47	2
999.8	34.5	43	2
1019.3	35	53	2
1038.6	35.5	71	2
1057.9	36	65	2
1077.5	36.5	62	2
1097.2	37	46	2
1116.8	37.5	52	2
1135.9	38	37	2
1154.9	38.5	46	2
1173.7	41	70	2
1192.6	41.5	61	2
1211.6	42	35	2
1230.7	42.5	48	2
1249.6	43	70	2
1268.7	43.5	56	2
1288.2	44	64	2
1307.7	44.5	77	2
1327.2	45	41	2
1338.8	45.5	98	2
1350.4	46	69	2
1362	46.5	66	2
1373.6	47	55	2
1385.2	47.5	45	2
1396.9	48	65	2
1408.5	48.5	74	2
1420.2	49	36	2
1431.6	49.5	45	2

1443	50	63	2
1453	50.5	82	2
1463	51	72	2
1473.1	51.5	12	2
1483.3	52	84	2
1493.6	52.5	71	2
1503.9	53	84	2
1514.2	53.5	70	2
1524.5	54	68	2
1534.5	54.5	59	2
1544.7	55	38	2
1551.9	55.5	47	2
1559.2	56	47	2
1566.5	56.5	64	2
1573.8	57	56	2
1581.1	57.5	68	2
1588.4	58	68	2
1595.8	58.5	58	2
1603.2	59	39	2
1610.5	59.5	56	2
1617.8	60	64	2
1625.4	60.5	69	2
1633.3	61	66	2
1641	61.5	79	2
1649	62	82	2
1656.8	62.5	60	2
1664.5	63	46	2
1672.2	63.5	36	2
1680.1	64	50	2
1687.8	64.5	56	2
1695.5	65	82	2
1702.2	65.5	72	2
1708.8	66	54	2
1715.5	66.5	53	2
1722.1	67	47	2
1728.8	67.5	45	2
1735.4	68	47	2
1742.1	68.5	45	2
1748.5	69	54	2

1755	69.5	53	2
1761.6	70	58	2
1768.8	70.5	70	2
1776.1	71	40	2
1783.6	71.5	53	2
1791	73	70	2
1798.4	73.5	55	2
1805.8	74	61	2
1813.2	74.5	64	2
1820.6	75	124	2
1828.1	76	57	2
1835.5	76.5	37	2
1846.6	77	54	2
1857.9	77.5	55	2
1869.2	78	57	2
1880.6	78.5	63	2
1891.7	79	54	2
1902.8	79.5	63	2
1914	80	60	2
1925.2	80.5	60	2
1936.3	81	61	2
1947.4	81.5	81	2
1952.5	82	47	2
1957.8	82.5	78	2
1963	83	79	2
1968.3	83.5	75	2

3LP18 – Three Lakes Peak 2018 Cores A, B, & C

Age (cal yr BP)	Sediment Depth (cm)	Charcoal Count (# particles >125 μ)	Sediment Volume (cm³)
2030.2	84	32	2
2038.9	85	52	2
2047.6	86	38	2
2055.8	87	53	2
2063.8	88	38	2
2071.7	89	42	2
2079.5	90	41	2
2087.5	91	102	2

2096.1	92	164	2
2104.7	93	65	2
2113.1	94	93	2
2121.2	95	82	2
2129.5	96	81	2
2137.9	97	84	2
2146.4	98	65	2
2154.6	99	68	2
2163.1	100	81	2
2171.6	101	97	2
2179.5	102	132	2
2187.6	103	117	2
2195.7	104	103	2
2203.7	105	113	2
2211.8	106	92	2
2219.8	107	106	2
2227.8	108	104	2
2236	109	83	2
2243.9	110	67	2
2252	111	32	2
2260.1	112	80	2
2268.5	113	53	2
2276.8	114	41	2
2285.4	115	49	2
2293.7	116	69	2
2305.1	117	59	2
2316.6	118	70	2
2328.3	119	53	2
2340.1	120	48	2
2352.1	121	40	2
2393.1	122	32	2
2434.2	123	41	2
2475.5	124	43	2
2516.8	125	22	2
2557.7	126	58	2
2599.1	127	33	2
2640.7	128	40	2
2682.5	129	56	2
2723.8	130	46	2

2764.6	131	19	2
2804.3	132	31	2
2843.9	133	32	2
2883.7	134	63	2
2923.7	135	15	2
2963.8	136	38	2
2991.9	137	39	2
3020.2	138	30	2
3048.6	139	54	2
3076.9	140	64	2
3105.3	141	80	2
3131.5	142	57	2
3157.5	143	54	2
3183.8	144	31	2
3209.9	145	32	2
3235.7	146	85	2
3263.2	147	24	2
3290.8	148	35	2
3318.6	149	55	2
3346.3	150	27	2
3373.7	151	19	2
3401	152	50	2
3428.4	153	57	2
3455.5	154	58	2
3482.6	155	43	2
3509.6	156	52	2
3534.9	157	29	2
3560.8	158	43	2
3586.8	159	53	2
3613.1	160	49	2
3639.3	161	33	2
3662.4	162	47	2
3685.3	163	47	2
3708.8	164	20	2
3732.7	165	41	2
3756.2	166	35	2
3769.5	167	48	2
3782.6	168	41	2
3795.9	169	72	2

3809.1	170	42	2
3822.5	171	29	2
3847.2	172	25	2
3871.9	173	19	2
3896.6	174	25	2
3921.3	175	45	2
3946.1	176	38	2
3972.7	177	54	2
3999.3	178	51	2
4026.2	179	53	2
4052.8	180	31	2
4078.2	181	40	2
4104.7	182	39	2
4131.1	183	27	2
4157.6	184	11	2
4183.5	185	45	2
4209.5	186	54	2
4235.5	187	25	2
4261.3	188	47	2
4287.4	189	45	2
4313.3	190	20	2
4339.3	191	18	2
4364.7	192	32	2
4390.4	193	55	2
4416.3	194	46	2
4442.3	195	59	2
4468.3	196	57	2
4494.9	197	57	2
4521.1	198	50	2
4547.7	199	64	2
4574.3	200	67	2
4600.6	201	94	2
4626.8	202	79	2
4653.4	203	21	2

APPENDIX C

POLLEN KEY

HAPLOXYLON	H
DIPLOXYLON	D
PINUS UNDIFF	P
PICEA	PI
ABIES	AB
PSEUDOTSUGA/LARIX	PL
CUPRESSACEAE	CU
ALNUS	AL
SALIX	SA
QUERCUS	QU
AMELANCHIER	AM
CEANOTHUS	CE
ARCEUTHOBIMUM	AR
SARCOBATUS	SA
POACEAE	POA
ARTEMESIA	ART
TUBIFLORAE	TUB
LIGULIFLORAE	LIG
AMARANTHACEAE	AMT
POLYGONUM TYPE	PB
BRASSICACEAE	BR
ROSACEAE	ROS
ERICACEAE	ER
AMBROSIA	AMB

EPHEDRA	EPH
BETLUACEAE	BET
RHAMNACEAE	RHA
GALIUM GA	GA
ONAGRACEAE	OG
RANUNCULACEAE	RAN
LAMIACEAE	LAM
ACERACEAE	ACE
ARCETHOBIUM	ARC
PTERIDIUM UNDIFF	PTE
INDETERMINATE	IND
UNKNOWN	UNK
APIACEAE	AP
SCROPHULARIACEAE	SCR
SHEPHERDIA CANADENSIS	SC
CYPERACEAE	CYP
POLYGONUM	AMPHIBIUM PGA
TYPHA	TYP
UNKNOWN AQUATIC	UNKAQ
PEDIASTRUM	PED
LYCOPODIUM	LY

APPENDIX C

RAW POLLEN COUNTS

MLM15

Age (cal yr BP)	Depth (cm)	H	D	P	PI
544.3	5.0	72	24	215	7
599.3	6.0	13	136	95	17.5
765	9.0	15	74	175.5	12
820	10.0	33	51	194.5	9
851.3	12.0	128	16	169	12
888.9	14.5	34	55	171.5	7
919.8	16.5	15	66	160.5	8.5
943.4	18.0	35	60	181	10
1030.1	21.0	9	98	164	18.5
1253.9	25.0	41	39	113.5	52.5
1422.4	26.0	33	51	173.5	9.5
1676.2	27.5	77	51	158	5
2013.3	29.5	27	66	189	12
2341.7	32.5	56	63	121	6
2538.2	34.5	24	75	189.5	3.5
2723.5	36.5	33	65	131.5	20.5
2860.9	38.0	21	79	180.5	9.5
3131.8	41.0	24	48	147	17
3307.9	43.0	21	75	229	13.5
3485.6	45.0	56	33	143.5	29
3768.9	48.5	70	28	121.5	36.5
3996.8	53.0	22	71	144.5	23.5
4066.7	55.0	20	60	155	21
4142.3	57.0	8	51	143.5	8.5
4282.8	61.0	38	46	195.5	26.5
4403	65.0	25	50	157	13.5
4463.1	67.0	9	45	220.5	4
4523.7	69.0	8	58	159.5	18.5
4654.9	73.0	16	49	164	11.5
4796.8	77.0	16	74	116.5	9.5
4945.6	81.0	22	57	149	7.5
5095.7	85.0	13	48	105	1.5
5247.9	89.0	16	50	144	4
5415.9	93.0	6	41	109	5.5

AB	PL	CU	AL	QU	AM
7.5	3	0	31	4	0
26	8	0	8	2	0
18.5	11	0	13	2	0
12.5	2	0	23	5	0
12	2	0	41	1	0
4	14	0	24	2	0
11.5	19	0	30	0	0
8.5	6	0	50	6	0
18	13	0	20	0	0
73	9	0	87	1	0
13	7	0	0	3	0
8.5	1	0	32	0	0
7.5	12	0	31	0	0
6	4	0	61	0	0
9.5	9	0	44	0	0
23.5	23	0	61	0	0
10	25	0	42	0	0
23	13	0	62	2	0
11.5	14	0	12	0	0
61.5	17	0	51	6	0
55.5	23	0	55	5	2
37	14	0	28	0	0
39.5	10	0	22	2	0
13.5	23	0	62	3	4
11.5	25	0	30	1	0
10	20	0	36	4	0
10.5	15	0	21	0	0
10.5	27	0	42	2	0
25	22	0	43	3	0
13	42	0	39	1	0
12	64	4	46	11	0
12.5	57	0	45	10	0
15	38	1	47	7	0
9	23	1	43	18	0

CE	SAR	POA	ART	BR	TUB
0	0	12	17	0	1
0	1	6	7	0	3
1	2	6	3	0	3
0	0	6	17	0	3
0	0	15	30	0	3
0	2	10	9	0	0
0	1	6	11	0	1
0	2	6	17	0	5
0	0	9	9	0	5
0	0	11	30	0	6
0	1	8	12	0	2
0	3	5	14	0	3
0	0	11	11	0	3
0	1	14	18	0	4
0	0	2	12	0	5
0	2	15	19	2	6
0	1	8	9	0	4
0	3	10	11	1	1
0	0	3	4	0	3
0	1	10	13	0	0
0	1	12	16	0	3
0	2	5	13	1	1
0	0	4	11	1	0
0	0	8	26	0	1
0	1	12	14	0	3
0	1	7	11	3	3
0	1	12	13	0	3
0	0	17	12	1	2
0	0	14	12	0	1
0	1	14	11	2	3
1	1	18	44	1	10
1	1	14	30	6	3
0	1	18	17	5	2
0	2	18	35	1	12

LIG	AMT	ER	ROS	AMB	BET
0	1	0	2	0	1
0	5	0	0	0	2
0	2	0	0	0	1
0	1	0	1	0	0
2	11	0	3	3	4
0	1	0	0	0	0
2	5	0	1	0	0
0	6	0	1	2	1
0	3	0	0	0	0
4	0	0	0	0	0
0	3	0	3	0	0
0	4	0	0	3	0
0	0	0	1	0	0
0	5	0	0	1	0
0	1	0	3	1	1
0	7	1	0	1	7
0	2	0	2	0	2
0	2	1	4	0	0
0	0	0	0	0	0
0	3	0	0	0	0
0	4	0	0	0	0
0	1	1	1	0	1
0	18	0	0	0	2
0	3	0	2	0	2
0	3	0	2	0	2
0	2	0	1	0	5
1	6	0	0	0	0
2	2	0	1	1	1
0	1	1	1	0	2
0	7	0	2	2	2
0	10	1	5	2	1
0	5	0	4	1	0
1	9	0	2	1	1
1	16	0	6	4	1

OG	GA	RAH	RAN	ARC	ACE
0	0	0	1	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	2	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	1	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
1	0	0	0	0	0
0	0	0	6	1	0
0	0	0	0	0	0
0	0	2	0	0	1
0	1	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	1
0	0	0	1	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
1	0	0	0	0	0
0	0	1	1	0	0
0	0	0	0	0	0
0	0	0	0	0	1
0	0	0	0	0	1
0	1	0	0	0	0
0	0	0	0	0	0

EPH	PTE	IND	LY	CYP	TYP
2	0	2	17	0	0
0	1	0	19	0	0

1	0	0	11	0	0
0	0	0	15	0	1
0	0	4	22	0	2
0	0	0	25	0	0
0	0	0	18	0	1
1	0	0	14	0	0
0	0	3	14	3	2
0	0	0	19	0	0
0	0	0	35	0	1
0	0	0	32	0	1
0	0	0	24	0	3
0	0	1	32	0	0
2	0	0	36	0	1
1	0	4	20	2	0
0	0	0	46	0	0
0	0	2	21	1	0
0	0	0	16	0	0
0	0	0	15	2	4
1	0	0	24	0	0
2	0	1	23	0	0
0	0	0	14	1	0
1	0	0	31	1	1
0	0	3	29	2	1
1	0	2	18	41	0
0	0	0	41	0	0
0	0	1	26	126	1
0	0	2	22	96	0
0	0	0	30	0	0
0	0	0	30	210	0
0	0	0	34	226	2
1	0	0	41	170	0
1	0	0	84	290	1

[illegible]

3LP15/18 A, B, & C

Age (cal yr BP)	Depth (cm)	H	D	P	PI
34.1	3	25	59	163	7.5
229.6	8	26	56	226.5	10
422.1	13	20	53	198	9
607	18	15	30	181	18
738.3	23	39	33	132	30.5
839	28	33	42	171	20.5
918.5	31	16	62	191.5	14.5
1071.7	35	18	104	168.5	5
1275.1	39	21	52	171.5	8.5
1398.1	43	16	92	141.5	13
1484.4	47	20	78	208.5	14.5
1616.4	55	33	54	176	9
1681.6	59	80	8	152	14.5
1736.9	63	28	35	141	19
1790.8	67	13	67	136.5	8.5
1857.8	71	23	61	166	6.5
1996.1	79	16	39	167.5	4
2068	87	17	42	189.5	14.5
2093.9	89	10	69	156.5	3.5
2137.1	95	9	60	140.5	20
2171.6	99	15	72	163	13
2180.2	103	23	45	122.5	5.5
2205.8	111	14	45	127	10
2274	112	12	49	121	8.5
2282.6	116	22	31	163	12
2320.7	119	21	56	145	8
2357.2	124	26	67	174.5	13
2534.7	132	17	53	222	11
2848.1	140	22	31	205	7
3106.7	144	12	90	191.5	11.5
3212.2	148	23	47	220	10
3315.6	156	28	43	221.5	4.5
3526.4	162	14	46	186.5	5
3684.9	164	22	75	200.5	13
3732.7	166	12	51	140.5	6.5
3770.5	170	15	48	152.5	8
3824.5	178	11	57	114	3
4031.3	182	16	73	159.5	7.5
4138	186	5	48	191.5	8
4241.5	194	5	18	143.5	5
4451.2	198	15	50	102	7

4657	202	13	76	146.5	29
AB	PL	CU	AL	SA	QU
18.5	0	0	41	1	1
28	5	0	32	2	0
28.5	2	0	37	1	1
23.5	3	5	38	0	0
19.5	4	0	28	1	0
32.5	5	1	39	1	0
34	4	0	40	0	0
36	2	1	28	1	0
25.5	9	1	40	0	0
20	5	2	44	0	0
27	9	0	32	0	0
34.5	6	0	43	2	0
21.5	11	0	38	1	0
26.5	4	1	43	0	0
13	4	0	50	0	0
16.5	5	0	39	1	0
15	7	1	71	2	0
14.5	9	0	63	0	0
12	6	0	50	1	0
14.5	2	1	79	0	0
13.5	11	0	89	0	0
7	6	2	96	0	0
11	6	0	102	0	0
22	3	2	74	2	0
7	8	1	61	1	0
14	5	0	108	0	0
12.5	8	0	82	0	0
15.5	4	1	48	0	0
16	7	0	61	0	0
15	4	0	45	1	0
27	10	0	65	0	0
19.5	5	1	91	0	0
14.5	11	0	83	0	0
12	4	0	103	2	0
7	4	2	84	1	2
11.5	8	0	107	0	0
19.5	4	1	114	1	0
10	5	0	79	0	0
5.5	5	0	94	0	0
7.5	2	0	162	0	1

5	10	0	118	1	2
16.5	8	2	64	0	0
AM	CE	SAR	POA	ART	BR
0	0	1	20	8	5
0	0	1	10	10	5
0	2	0	18	14	7
0	0	0	19	10	2
0	0	1	11	15	2
0	0	0	5	11	0
0	0	0	25	15	0
0	0	2	12	13	0
0	0	1	10	26	1
0	0	2	4	11	0
1	0	0	8	15	0
1	1	0	17	23	0
0	0	0	12	14	0
0	0	4	8	17	0
0	0	0	10	9	3
0	0	1	8	14	0
0	0	1	15	17	0
0	0	1	10	19	0
0	0	0	10	12	3
0	0	0	14	15	0
0	0	2	5	19	3
1	1	1	19	20	0
0	2	1	13	24	0
1	2	1	19	10	1
0	0	1	11	20	0
0	0	0	12	16	0
0	0	0	7	18	0
0	0	0	6	15	0
0	0	1	7	21	0
0	0	2	4	14	4
2	1	0	20	17	0
0	0	0	17	20	0
0	0	0	18	17	0
0	0	0	19	12	0
0	0	0	13	17	1
0	0	1	20	15	0
1	0	0	17	16	0
0	0	1	6	2	0
0	0	0	17	15	0

1	2	0	23	12	1
0	0	2	11	13	0
0	0	1	16	18	3
TUB	LIG	PB	AMT	ER	ROS
2	1	0	5	0	6
7	1	0	2	0	1
0	0	0	2	1	0
1	0	0	1	1	0
3	0	0	1	0	2
1	0	0	6	1	2
2	0	0	3	0	0
4	0	1	0	1	1
7	0	0	1	1	2
3	0	1	3	1	2
2	0	0	2	2	3
2	0	0	1	1	1
6	0	0	1	4	0
3	0	0	1	2	1
4	0	0	3	3	1
3	0	0	1	0	2
0	0	0	2	0	4
5	0	0	0	0	3
5	0	0	0	0	9
4	0	0	2	0	3
5	0	0	4	6	3
6	0	1	2	3	1
7	0	0	2	2	3
6	0	1	1	1	2
4	0	1	3	0	2
5	1	1	0	0	3
5	0	0	3	0	2
2	1	0	0	1	3
1	0	2	1	1	0
5	0	0	1	2	3
2	0	0	2	2	0
2	0	0	0	2	3
4	0	0	3	1	4
4	0	2	2	2	7
4	0	2	3	2	8
7	0	1	3	0	7
3	0	2	1	0	0
7	0	0	3	3	0

5	0	0	0	1	4
6	0	1	0	0	7
7	3	0	2	1	4
4	0	0	3	0	1

AMB	BET	OG	GA	RAH	RAN
0	1	0	0	0	0
1	1	0	0	0	1
0	0	0	0	0	0
0	0	0	0	0	0
0	1	0	0	0	0
1	1	0	0	0	0
0	0	0	0	0	1
0	0	0	0	0	0
0	1	0	0	0	0
0	0	0	1	1	0
0	0	0	0	0	0
0	0	0	0	1	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	1
0	0	1	0	0	0
0	0	0	0	1	0
0	0	0	0	0	2
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	1	1
0	0	0	0	0	0
0	0	0	0	0	0
1	1	0	0	0	0
0	1	0	0	0	1
0	0	0	0	0	1
0	0	0	0	0	0
0	0	0	0	0	1
0	0	0	0	0	0
0	0	0	0	2	1
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	2
0	0	0	0	0	0
0	0	0	0	0	1

0	0	0	0	0	0
2	0	0	0	0	1
0	1	0	0	0	0
0	2	0	0	0	1
2	0	0	0	0	1
1	0	0	0	1	1
LAM	SCR	AP	IND	LY	CYP
0	1	0	5	17	0
0	0	0	2	13	0
0	0	0	0	5	0
0	0	2	0	12	1
0	0	0	0	13	2
1	0	0	1	13	0
0	0	0	5	12	1
0	0	0	0	19	0
0	0	0	3	17	2
0	0	0	0	7	0
0	0	0	2	19	1
0	0	0	1	17	1
0	0	0	0	14	3
0	0	0	0	15	0
0	0	0	1	9	1
0	0	0	0	16	0
0	0	0	6	7	0
0	0	0	1	14	0
0	0	0	0	13	0
0	0	0	0	6	4
0	0	0	0	12	0
0	0	0	3	6	0
0	0	0	0	12	0
0	0	0	2	16	1
0	0	0	0	14	1
0	0	0	3	16	0
0	0	0	0	10	0
0	0	0	5	11	1
0	0	0	0	14	0
0	0	1	0	11	0
0	0	0	0	14	0
0	0	0	0	16	2
0	0	0	0	9	0
0	0	0	2	16	1
0	0	0	1	10	0

0	0	0	2	19	0
0	0	0	7	10	2
0	0	0	0	9	0
0	0	0	0	5	1
0	0	0	4	9	0
0	0	1	0	9	0
0	0	0	5	25	0

TYP	UNKAQ
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
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0	0
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0	2
0	0
0	0