

FOREST DISTURBANCE HISTORY IN THE SAWTOOTH  
MOUNTAINS OF CENTRAL IDAHO AND THE  
BEAVERHEAD RANGE OF  
WESTERN MONTANA

by

Joshua Albert Gage

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

of

Master of Science

in

Earth Sciences

MONTANA STATE UNIVERSITY  
Bozeman, Montana

November 2008

©COPYRIGHT

by

Joshua Albert Gage

2008

All Rights Reserved

APPROVAL

of a thesis submitted by

Joshua Albert Gage

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency, and is ready for submission to the Division of Graduate Education.

Dr. Cathy Whitlock

Approved for the Department of Earth Sciences

Dr. Stephan Custer

Approved for the Division of Graduate Education

Dr. Carl A. Fox

## STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Joshua Albert Gage

November 2008

## ACKNOWLEDGEMENTS

Firstly, I thank my primary advisor, Dr. Cathy Whitlock who suggested the ideas for the thesis study, provided funding, assisted in fieldwork, helped with interpretation of the results, commented on various forms of the thesis and was forever patient throughout the course of my study. I thank my other committee members, Jesse Logan and Kathy Hansen who provided their expertise and guidance throughout this process.

Eric Grimm of the Illinois State Museum, provided the Reservoir Lake record and he and his wife Jane opened the doors of their home to me when I visited Springfield. Pietra Mueller in Springfield worked tirelessly in sampling and preparing the Reservoir Lake chronology. I thank Dr. Allan Ashworth from North Dakota State University and Dr. Donald Bright from Colorado State University who helped to interpret insect fragments. Robin Garwood of the Sawtooth National Forest assisted with funding, logistics and her expertise of the Sawtooth Mountains. Andrea Brunelle provided her paleo-data from Pintlar Lake. Christy Briles provided pollen data from Decker Lake. I am grateful to my field assistants including Peter Ramos, Stephanie Mumma, Cathy Whitlock, Matias Fernandez and Anne & Kintla Schrag. My lab assistants including Whitney Brawner and Ashley Peery. I thank the post-doc researchers and other masters student in the lab including Dr. Phillip Higuera, Dr. Dave McWethy, Dr. Christy Briles, Mariana Huerta and Virginia Iglesias. I thank the funders of this project including USFS Coop Agreement and DOE INRA grant. Finally to my friends and family and especially to Anne Schrag for being forever patient and loving during the hard times throughout this process.

## TABLE OF CONTENTS

|                                                                                                                                                   |    |
|---------------------------------------------------------------------------------------------------------------------------------------------------|----|
| 1. THESIS OVERVIEW .....                                                                                                                          | 1  |
| References .....                                                                                                                                  | 7  |
| 2. ACCUMULATION OF MOUNTAIN PINE BEETLE FRAGMENTS IN SMALL LAKES DURING<br>AND FOLLOWING A RECENT OUTBREAK IN THE SAWTOOTH MOUNTAINS, IDAHO ..... | 9  |
| Introduction .....                                                                                                                                | 9  |
| Methods .....                                                                                                                                     | 11 |
| Results .....                                                                                                                                     | 14 |
| Discussion .....                                                                                                                                  | 20 |
| Conclusions.....                                                                                                                                  | 25 |
| References Cited.....                                                                                                                             | 27 |
| 3. COMPARING LATE HOLOCENE FIRE HISTORIES FROM THREE LAKE SEDIMENT<br>RECORDS IN THE SAWTOOTH MOUNTAINS, IDAHO .....                              | 29 |
| Introduction .....                                                                                                                                | 29 |
| Methods .....                                                                                                                                     | 33 |
| Results .....                                                                                                                                     | 36 |
| Discussion .....                                                                                                                                  | 42 |
| 2000-1200 cal yr BP (BC 50 – 750 AD) .....                                                                                                        | 46 |
| 1200-600 cal yr BP (AD 750 - 1350) .....                                                                                                          | 46 |
| 600 cal yr BP – present (AD 1350 – 2005) .....                                                                                                    | 49 |
| Conclusions.....                                                                                                                                  | 51 |
| References Cited.....                                                                                                                             | 54 |
| 4. AN ANALYSIS OF HIGH-RESOLUTION RECORDS OF HOLOCENE FIRE FROM THE<br>NORTHERN ROCKY MOUNTAINS, USA .....                                        | 58 |
| Introduction .....                                                                                                                                | 58 |
| Methods .....                                                                                                                                     | 63 |
| Results .....                                                                                                                                     | 68 |
| Discussion .....                                                                                                                                  | 71 |
| Late Glacial Period > 11000 cal yr BP .....                                                                                                       | 71 |
| Early Holocene Period (11000 – 6000 cal yr BP).....                                                                                               | 73 |
| Middle Holocene Period (6000 – 2500 cal yr BP) .....                                                                                              | 76 |
| Late Holocene Period (2500 cal yr BP – present) .....                                                                                             | 77 |
| Conclusions.....                                                                                                                                  | 79 |
| References Cited.....                                                                                                                             | 82 |

## TABLE OF CONTENTS CONT.

|                                                                  |     |
|------------------------------------------------------------------|-----|
| 5. CONCLUSIONS .....                                             | 87  |
| APPENDICES .....                                                 | 90  |
| APPENDIX A: Important Correspondences In relation to thesis..... | 91  |
| APPENDIX B: Raw Charcoal Data .....                              | 95  |
| APPENDIX C: Sites Visited for Thesis Chapter 2 .....             | 145 |

## LIST OF TABLES

| Table                                                                           | Page |
|---------------------------------------------------------------------------------|------|
| 2.1. Sites visited during field season .....                                    | 15   |
| 2.2. Insect parts identified by Dr. Allan Ashworth .....                        | 16   |
| 2.3. Number of insect parts found at each depth .....                           | 18   |
| 2.4. Sites analyzed for insect parts .....                                      | 20   |
| 3.1. $^{210}\text{Pb}$ activity and age determinations .....                    | 38   |
| 4.1. Age information used for chronologies at Reservoir and Pintlar lakes ..... | 65   |

## LIST OF FIGURES

| Figure                                                                                                                                               | Page |
|------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 2.1. Map of chapter 2 Study area .....                                                                                                               | 13   |
| 2.2. Figure illustrating sampling patterns at Martha and Decker lakes.....                                                                           | 19   |
| 3.1. Map of chapter 3 study area.....                                                                                                                | 32   |
| 3.2. Calibrated age vs. depth curves .....                                                                                                           | 39   |
| 3.3. Carbonate and organic percentages, charcoal concentration, lithology and age<br>Determinations from Cape Horn II, Hidden and Decker lakes ..... | 41   |
| 3.4. Charcoal accumulation rates .....                                                                                                               | 42   |
| 3.5. Fires in the Sawtooth National Forest since 1950 .....                                                                                          | 45   |
| 3.6. Simplified patterns of burning .....                                                                                                            | 47   |
| 3.7. Boxplots of fire-return intervals .....                                                                                                         | 48   |
| 4.1. Map of study region.....                                                                                                                        | 62   |
| 4.2. Age vs. depth relationships.....                                                                                                                | 67   |
| 4.3. Lithology <sup>14</sup> C dates, charcoal concentration and charcoal accumulation rates .....                                                   | 68   |
| 4.4. Fire history information for Reservoir and Pintlar lakes.....                                                                                   | 69   |
| 4.5. Pollen record from Pintlar Lake .....                                                                                                           | 72   |
| 4.6. Simplified patterns of fire activity at Reservoir and Pintlar lakes .....                                                                       | 75   |

## ABSTRACT

Studies of disturbance history are important because they provide a framework for understanding the ecological response to past, present, and future climate change, and this information is useful for paleoecological researchers and land-use managers. Fire and insect outbreaks are common occurrences in western forests, and three studies were undertaken to increase our knowledge of their history in the northern Rocky Mountains. In the first study, sediment cores were sampled from 21 lakes located in forests experiencing mountain pine beetle infestation in the Sawtooth Mountains, Idaho. Cores were analyzed to determine whether or not mountain pine beetle remains were accumulating in the lake sediments in association with recent outbreaks. The study found that insect remains were sparse in the lake sediments, even in sites surrounded by heavily infested forests. These results cast doubt on whether paleo-beetle records can be reconstructed from lake-sediment cores. In the second study, one-meter-long sediment cores were taken from three lakes in *Pinus contorta* forests in the Sawtooth Mountains, Idaho, to reconstruct a historical record of fire spanning the last 2000 years. High-resolution charcoal analysis of the cores indicated changes in fire activity, but there was not a significant difference in fire occurrence during the relatively dry Medieval Climate Anomaly (1050 – 650 cal yr BP), the cooler Little Ice Age (750 – -50 cal yr BP), and the present day. Results suggest that the current fire regime has persisted for at least 2000 years, with little modification by humans or climate. In the third study, a high-resolution charcoal record was analyzed from Reservoir Lake in the Beaverhead Mountains, Montana to reconstruct the fire history of the last 15,000 years at the lower forest-steppe boundary. The charcoal record indicates relatively low fire frequency between 13,500 cal yr BP and 6000 cal yr BP and increased fire activity from 6000 to 1500 cal yr BP, suggesting increasing aridity in the middle and late Holocene. The fire-climate linkages observed in the paleoecological record provide insights that are useful in understanding future fire regimes with projected climate changes.

## CHAPTER 1

## THESIS OVERVIEW

Introduction

Defining disturbance as a “natural” ecological process has been a subject of controversy amongst ecologists for many years (Sprugel, 1991). Early views on ecological disturbance suggested it was a starting point for species succession, which would eventually lead to a climax community (Clements, 1916). Successional processes were postulated to be reset by a disturbance and proceed in a linear order of (1) nudation, (2) migration, (3) establishment, (4) competition, (5) reaction and, finally, (6) stabilization or climax (Clements, 1916). Defining disturbance as a natural and possibly integral part of ecosystem dynamics that could moderate a plant community was not proposed until a study of Isle Royale, Michigan, by Cooper (1913). Cooper investigated forest stands throughout the island, noting that stands of all ages and successional classes were present and that ‘The forest as a whole remains the same, the changes in various parts balancing each other.’(Cooper, 1913). However, it took decades before ecologists began to accept disturbance as a natural process, critical in some types of ecosystems.

Even in the 1930s, the Clementsian viewpoint was that disturbance was an impediment to the development of a climax community (Sprugel, 1991). Weavers and Clements (1939), for example, described lodgepole pine (*Pinus contorta*) in Colorado as

a 'forest weed-tree which grows very rapidly', suggesting that it was not an integral part of the ecosystem. They speculated the repeated burns would result in an area being continuously occupied by lodgepole pine, a very inferior commercial type of forest.' (Weaver and Clements, 1939).

In the early 1970s, a number of studies recognized the importance of disturbance in maintaining the composition of ecological communities. Using tree rings to reconstruct past fire regimes in Montana and Minnesota, as well as using historical records of fire in the chaparral of California, investigators began to understand disturbance as a process that is integral to maintaining community integrity (Habeck and Mutch, 1973; Heinzelman, 1973; Hanes, 1971). Habeck and Mutch (1973) considered fire-dependent forests as being in an 'equilibrium or a kind of biologic "checks and balances" system that governed the magnitude of the effects accompanying a given forest fire.' (Habeck and Mutch, 1973). The results of many of these studies were parallel to those of Cooper's Isle Royale study (Cooper, 1913) and established disturbance as a natural process that maintained ecological communities rather than resetting successional pathways (Sprugel, 1991).

Disturbance events vary based on their frequency, size and severity, all of which, in turn, influence post-disturbance succession. The 1988 fires in Yellowstone National Park, for example, burned in a mosaic pattern across the landscape. Colonization of vegetation following the fires varied based on the size of the burned patch and the intensity of the fire (Turner et al., 2003). In the years following the fires, areas that

burned at a moderate severity had more lodgepole pine seedlings than did severely burned patches. Severe fires reduced the vitality of seeds and resulted in reduced establishment of seedlings (Turner et al., 2003). Large fires led to increased seedling establishment as compared with smaller patches which showed less seedling establishment (Turner et al., 2003).

Ecosystem response may also be influenced by the size and frequency of a disturbance. Romme et al. (1998) developed a heuristic model to explain ecosystem response following large infrequent disturbance (LID) events. Their study classified possible responses to LIDs as being (1) threshold, (2) scale-independent and (3) continuous (Romme et al., 1998). A threshold response occurs when the magnitude, severity, intensity or duration exceeds a level that initiates a very different ecosystem response. An example of a threshold response would be diminished seedling establishment following the 1988 fires in Yellowstone. Once a certain threshold in fire severity was crossed, seed vitality was reduced resulting in decreased establishment following the fires (Turner et al., 2003).

Scale-independent responses, in contrast, produce an ecological outcome that remains constant regardless of disturbance size. For example, the lodgepole pine forests of YNP experienced fires of varying size and severity for thousands of years (Millspaugh et al., 2000; Romme and Despain, 1989), and yet these forests maintain relatively homogenous stand characteristics. A continuous response occurs when the ecosystem change is proportional to the magnitude, severity or intensity of the

disturbance. Romme et al. (1998) indicate that a continuous response is difficult to observe in nature but is hypothetically possible.

Wildfires along with other disturbance agents (Dale et al., 2001) are one of the most significant forms of natural disturbance in the Rocky Mountains. Fires shape forest composition and aid in nutrient cycling (Boerner, 1982). Although fire is a natural process that has been operating for millions of years, the frequency and severity of wildfire has increased in recent decades. Recent shifts in fire regime are attributed to management practices (Veblen et al., 2000) as well as the result of climate changes, including earlier snowmelt and a longer wildfire season (Westerling et al., 2006). Moreover, increasing temperatures are projected in the future and likely to further increase the frequency of wildfires in the Rocky Mountain region (IPCC, 2007).

Other natural disturbances in Rocky Mountains include severe storms, mass-wasting events, flooding, volcanic eruptions, and insects and other pathogens (Agee, 1993). In lodgepole forests, mountain pine beetle (MPB; *Dendroctonus ponderosae*) infestations have reached epidemic levels in many areas of the western United States and Canada. From 1999 to 2002, the total area affected by mountain pine beetle in the Sawtooth Mountains, central Idaho, increased from 3300 to 342000 hectares (USFS, 2006). In 2006, over 100,000 km<sup>2</sup> of western Canadian forest were infested by mountain pine beetle (Westfall, 2007). If current infestation rates continue there, 80% of mature lodgepole pine (*Pinus contorta*) trees will be dead by 2013 (Westfall, 2007).

The magnitude of these MPB outbreaks is unprecedented and well outside the range of previously observed outbreaks (USFS, 2006; Westfall, 2007).

In order to better understand disturbance processes and interactions over longer periods of time (i.e. hundreds and thousands of years), historical records of disturbance are needed. Records of fire from tree rings provide histories of fire over periods of hundreds and sometimes thousands of years (Huffman et al., 2008; Arsenault et al., 2007). Records of fire derived from lake-sediment charcoal extend back tens of thousands of years and provide a temporal perspective of fire not attainable from tree-ring records (Turner et al., 2008; Walsh et al., 2008). One study in particular has attempted to use mountain pine beetle fossils from lake sediments to reconstruct paleo-records of beetle outbreak (Brunelle et al., 2007).

The goals of this thesis will be to reconstruct histories of fire at different time scales and to investigate if mountain pine beetles accumulate in lake sediments following an outbreak. The second chapter of this thesis will address the mountain pine beetle question through a study of lake sediment records. This chapter investigates sediment samples from sites in the Sawtooth Mountains, Idaho which have recently undergone severe infestation of mountain pine beetle. The third chapter of this thesis will continue to focus on the Sawtooth Mountains, Idaho and will investigate fire history over the last 2000 years. Three lake sediment records from similar forests will be compared to assess the spatiotemporal patterns of fire in the region. The final chapter of this thesis will look at fire over longer periods of time (i.e. 15,000 years) in the

Northern Rocky Mountains, USA. This long record of fire will be compared to other records of fire and vegetation in the area and compared to regional climate variations during this time period.

### References Cited

- Agee, J. K. (1993). Fire ecology of the Pacific Northwest. Island Press, Washington, DC.
- Arseneault, D., Boucher, E., and Bouchon, E. (2007). Asynchronous forest-stream coupling in a fire prone boreal landscape: insights from woody debris. *Journal of Ecology*. 95. 789-01.
- Boerner, R. E. J. (1982). Fire and Nutrient Cycling in Temperate Ecosystems. *BioScience* 32, 187-192.
- Brunelle, A., Rehfeldt, G. E., Bentz, B., and Munson, A. S. (2007). Holocene records of *Dendroctonus* bark beetles in high elevation pine forests of Idaho and Montana, USA. *Forest Ecology and Management*.
- Clements, F. E. (1916). "Plant Succession: An Analysis of the Development of Vegetation." Carnegie Institution of Washington.
- Cooper, W. S. (1913). The Climax Forest of Isle Royale, Lake Superior, and Its Development. III. *Botanical Gazette* 55, 189-235.
- Dale, V.H., Joyce, L.A., McNulty, S., Neilson, R.P., Ayres, M.P., Flannigan, M.D., Hanson, P.J., Irland, L.C., Lugo, A.E., Peterson, C.J., Simberloff, D., Swanson, F.J., Stocks, B.J., and Wotton, B.M. (2001). Climate Change and Forest Disturbance. *Bioscience* 51. 723-734.
- Habeck, J. R., and Mutch, R. W. (1973). Fire-dependent forests in the northern Rocky Mountains. *Quaternary Research* 3, 408-424.
- Hanes, T. L. (1971). Succession after Fire in the Chaparral of Southern California. *Ecological Monographs* 41, 27-52.
- Heinselman, M. L. (1973). Fire in the Boundary Waters Canoe Area, Minnesota. *Quaternary Research* 3, 329-382.
- Huffman, D.W., Fulé, P.Z., Crouse, K.M. and Crouse, J.E. (2008). Fire history of pinyon-juniper woodlands at upper ecotones with ponderosa pine forests in Arizona and New Mexico. *Canadian Journal of Forest Research*. 38. 2097-2108.
- Millsbaugh, S. H., Whitlock, C., and Bartlein, P. J. (2000). Variations in fire frequency and climate over the past 17 000 yr in central Yellowstone National Park. *Geology* 28, 211-214.

Romme, W. H. (1998). Are Large, Infrequent Disturbances Qualitatively Different from Small, Frequent Disturbances? *Ecosystems* 1, 524-534.

Romme, W. H., and Despain, D. G. (1989). Historical Perspective on the Yellowstone Fires of 1988. *BioScience* 39, 695-699.

Sprugel, D. G. (1991). Disturbance, equilibrium, and environmental variability: What is "natural" vegetation in a changing environment? *Biological Conservation* 58, 1-18.

Turner, M. G., Romme, W. H., and Gardner, R. H. (1999). Prefire heterogeneity, fire severity, and early postfire plant reestablishment in subalpine forests of Yellowstone National Park, Wyoming. *International Journal of Wildland Fire* 9, 21-36.

Turner, M. G., Romme, W. H., and Tinker, D. B. (2003). Surprises and lessons from the 1988 Yellowstone fires. *Frontiers in Ecology and the Environment* 1, 351-358.

Turner, R., Roberts, N., and Jones, M.D. (2008). Climatic pacing of Mediterranean fire histories from lake sedimentary microcharcoal. *Global and Planetary Change*. 63. 317-324.

Veblen, T. T., Kitzberger, T., and Donnegan, J. (2000). Climatic and Human Influences on Fire Regimes in Ponderosa Pine Forests in the Colorado Front Range. *Ecological Applications* 10, 1178-1195.

Walsh, M.K., Whitlock, C., and Bartlein, P.J. (2008). A 14,300-year-long record of fire-vegetation-climate linkages at Battle Ground Lake, southwestern Washington. *Quaternary Research*. 70. 251-264.

Weaver, J. E., and Clements, F. E. (1938). "Plant ecology." McGraw-Hill Book Company, inc.

Westerling, A. L., Hidalgo, H. G., Cayan, D. R., and Swetnam, T. W. (2006). Warming and earlier spring increase western US forest wildfire activity. *Science* 313, 940-943.

Westfall, J. (2007). 2006 Summary of Forest Health Conditions in British Columbia. British Columbia Ministry of Forests and Range, Victoria.

## CHAPTER 2

ACCUMULATION OF MOUNTAIN PINE BEETLE FRAGMENTS IN SMALL LAKES  
DURING AND FOLLOWING A RECENT OUTBREAK  
IN THE SAWTOOTH MOUNTAINS, IDAHOIntroduction

Although relatively small in size (4-7 mm), the mountain pine beetle (*Dendroctonus ponderosae*) can cause a substantial impact on the forested ecosystems of the western United States. Mountain pine beetle kills its hosts by eating the living layer (phloem) of trees and effectively girdling them (Amman and Cole, 1983). The relationship between mountain pine beetle and wildfires may be important as well, and a recent study suggests that the intricacies of these two disturbance processes are poorly understood and warrant further research (Romme et al., 2008).

Because insects are ectothermic, their life cycles are inherently linked to temperature. Mountain pine beetle outbreaks have been linked to changes in suitable thermal habitat for mountain pine beetle (Carroll et al., 2003). Projected climate change in the Rocky Mountains is likely to increase the climate space of mountain pine beetle both northward (Logan et al., 1995) and upward into higher-elevation habitat (Logan and Bentz, 1999). Mountain pine beetle outbreaks, which are most common in western lodgepole pine forests (*Pinus contorta*), have been projected to expand eastward from British Columbia and become established in the boreal forests of central Canada (Logan and Powell, 2001). Although whitebark pine (*Pinus albicaulis*) offers suitable habitat for

mountain pine beetle outbreaks (Amman, 1982), the minimum temperature that characterizes whitebark-pine habitat is usually too low for an outbreak to flourish (Hicke et al., 2006). Recent evidence suggests that mountain pine beetle has now spread its range to higher elevations, impacting whitebark pine (Logan and Powell, 2001).

Whereas lodgepole pine has coevolved with mountain pine beetle and developed defense mechanisms to combat infestations, whitebark pine has not (Hicke et al., 2006).

Whitebark pine is a critical food source to many species, including Clark's nutcracker (*Nucifraga columbiana*), which disperses its seeds (Hutchins and Lanner, 1982), red squirrel (*Tamiasciurus hudsonicus*), and grizzly bear (*Ursus arctos horribilis*) (Mattson and Reinhart, 1997). Loss of stands of whitebark pine may seriously influence these other species that depend in its seeds as a food source.

Current outbreaks of mountain pine beetle are outside the range of documented records, but they may lie within the historical range of natural variability on longer time scales. One study of mountain pine beetle fossils from northern Idaho (Brunelle et al., 2007) suggests that, when beetle infestations reach epidemic levels, their remains are present in lake sediments. For example, insect outbreaks were inferred at 8331, 8410, 8529 and 7954 cal yr BP, based on the presence of mountain pine beetle remains in sediments dating to these times (Brunelle et al., 2007).

The intriguing results of this study require a better understanding of mountain pine beetle outbreaks and the deposition of insect remains in lake sediments. The questions I intend to address in this chapter are 1) How common are the remains of

mountain pine beetle and other insects in the sediments of small lakes? 2) Are the remains more abundant during times of widespread infestation, such that they might provide reliable documentation of past outbreaks?

This chapter describes the results a pilot study in the Sawtooth Mountains of central Idaho to test the feasibility of using insect remains in lake sediments to infer the occurrence of an mountain pine beetle infestation. My objectives in this study are to address the following questions: 1) is the current outbreak of mountain pine beetle in the Sawtooth Mountains registered by the presence of their remains in the surface sediments of small lakes in infested forest and 2) if so, could stratigraphic records of mountain pine beetle remains in lake sediments be used to reconstruct a historical record of past infestation in this region?

### Methods

Prior to beginning field work, lakes in areas affected by a mountain pine beetle outbreak were identified using a geographical information system (GIS). A polygon-layer of Idaho lakes was overlain on USDA Forest Service aerial detection survey (ADS) data to select sites within watersheds that experienced recent mountain pine beetle infestation (available online: <http://www.fs.fed.us/foresthealth/technology/gis.shtml#ADS>). ADS data come from annual flights by the USDA Forest Service and are a semi-quantitative assessment of which forest stands are affected by insects (Fig. 2.1). Lakes were identified for sampling based on their proximity to infected forest stands,

their small size, simple watershed characteristics, and accessibility. A total of 50 lakes within or near MBP-infected forests was identified for sampling during the field season (Fig. 2.1).

At each site, forest stands within the watershed were verified for signs of mountain pine beetle infestation, based visual assessment. Surface cores were collected from the first two lakes visited (Decker and Martha lakes) at nine and ten different locations in an attempt to identify whether upwind, downwind, near shore, and lake center would provide the best sampling location for other sites. At the other sites, a total of three cores were taken, one from the deepest water depth and two from littoral zones. Cores were taken from an inflatable raft using a Klein gravity corer that recovered the mud-water interface intact. The cores were extruded upwards, sampled at 2 cm intervals, and rinsed into whirlpak bags for storage. The samples were transported back the Montana State University Paleoecology Lab, where they were refrigerated before being analyzed. Sedimentation rates at Decker Lake were inferred from a sequence of  $^{210}\text{Pb}$  dates taken in the upper 20 cm of a short core from the Decker Lake (see chapter 4). The sedimentation rate at this site indicated that the upper 8 cm spanned the last 120 years at Decker Lake. Since the objective of this study was investigating the accumulation of insects following a recent outbreak, only the upper 6 cm were investigated from subsequent cores taken at other lakes.

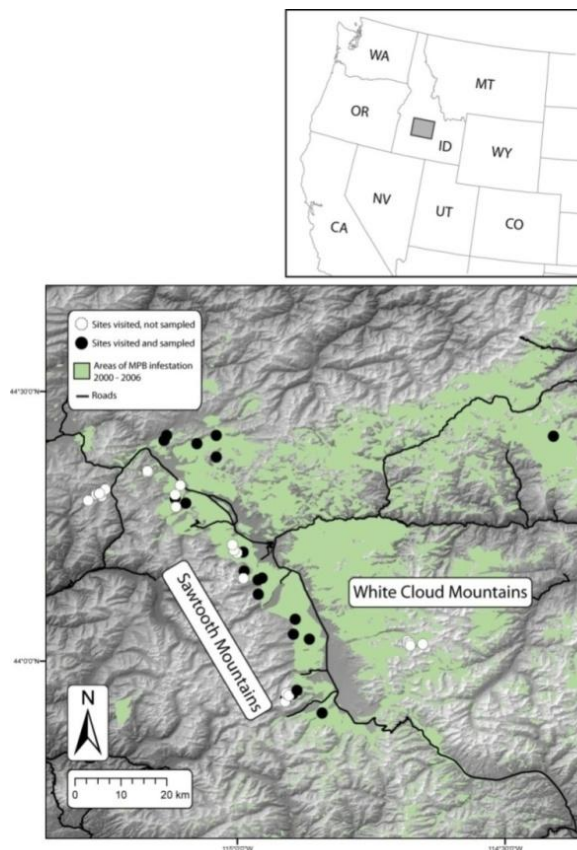


Figure 2.1. Map of study area indicating sites visited during field season and whether or not they were sampled. Green shading indicates forest stands infested by mountain pine beetle during 2005 and 2006.

Similar techniques of sediment deflocculation and processing were used in this analysis as those employed for the analysis of macroscopic charcoal in lake sediments (see chapter 3 of this thesis). Prior to treating sediments with sodium metaphosphate, beetles collected from beneath the bark of trees were soaked in sodium metaphosphate for a number of hours to ensure that they would not be disintegrated by the treatment.

Samples of  $10 \text{ cm}^3$  were taken from each 2-cm interval. The samples were treated with 5% sodium metahexaphosphate (a deflocculating agent) for 24 hours

before being washed through a 500- $\mu$ m-mesh sieve. Samples were then rinsed into petri dishes and examined under a stereoscope. Anything resembling an insect or insect part was removed, stored in ethyl alcohol (a preserving agent), and archived for later identification. Insect parts were photographed using a stereoscope coupled with a SPOT Insight digital camera, compiled on CD and sent to Dr. Allan Ashworth (North Dakota State University Department of Geosciences) for positive identification. Dr. Ashworth is an expert in identifying fossil beetles from sedimentary records.

### Results

Of the 44 sites visited during the field seasons of 2006 and 2007, only 21 were appropriate for sampling (Fig. 2.1; Table 2.1). Sites that were not sampled were either too dry or had no sign of mountain pine beetle infestation in the surrounding forest (Fig 2.1; see Appendix C for a list of unsampled sites).

ADS data indicate that the forests surrounding the sites were infested in 2004 and, when visited during 2006, average mortality was estimated at 70%. The forest surrounding Decker Lake had > 70% mortality. Nine 8-cm-cores were recovered from the lake. One core came from the deepest water of the lake and the others were taken in a grid pattern around the initial deep-water core (Fig. 2.2). A total of 34 insect parts were removed from the sediment samples (Table 2.3). Of these 34 insect parts, 23 were identified by Dr. Allan Ashworth (Table 2.2). Five were from the order Coleoptera (beetle), but could not be identified to a lower level (A. Ashworth, written comm.,

2007). There were two fragments from the order Hemiptera, eight of the samples came from the order Diptera (flies), and eight of the samples were classified as miscellaneous chitin.

Table 2.1. Sites visited and sampled during field season as well as qualitative and sampling information

| Name                              | Lat (° N) | Long (° W) | Elevation (m) | Water Depth (m) | Infestation Date | Dominant Tree Species Near Site <sub>1</sub> | Number of Cores | Core Length (cm) | Sampling Interval (cm) |
|-----------------------------------|-----------|------------|---------------|-----------------|------------------|----------------------------------------------|-----------------|------------------|------------------------|
| Decker Lake                       | 44.069    | 114.889    | 2167          | 6.25            | 2004             | pincon,psemen                                | 9               | 8                | 2                      |
| Martha Lake                       | 44.287    | 115.095    | 2075          | 3.00            | 2004             | pincon,psemen                                | 9               | 8                | 2                      |
| Sawtooth City Hellroaring Moraine | 43.894    | 114.838    | 2238          | 0.70            | 2002             | pincon                                       | 3               | 6                | 2                      |
| Goat Meadow                       | 44.032    | 114.862    | 2180          | 1.74            | 2001             | pincon                                       | 3               | 6                | 2                      |
| Marshall Lake                     | 44.195    | 114.987    | 2078          | 1.18            | 2003             | pincon                                       | 3               | 6                | 2                      |
| Hidden Lake                       | 44.159    | 114.985    | 2351          | 2.84            | 2002             | pincon,abilas                                | 3               | 6                | 2                      |
| Decker Lake 2                     | 44.296    | 115.115    | 2142          | 5.37            | 2005             | pincon                                       | 3               | 6                | 2                      |
| Cabin Creek 1                     | 44.071    | 114.892    | 2155          | 0.96            | 2004             | pincon                                       | 3               | 6                | 2                      |
| Cabin Creek 2                     | 43.917    | 114.906    | 2690          | 8.60            | 2005             | pinalb, pincon                               | 4               | 6                | 2                      |
| Running Cow Pond                  | 43.921    | 114.907    | 2775          | 5.60            | 2005             | pinalb, abilas                               | 3               | 6                | 2                      |
| Big Bench                         | 43.929    | 114.894    | 2630          | 2.25            | 2005             | pincon, pinalb                               | 3               | 6                | 2                      |
| Lil Bench                         | 44.116    | 114.959    | 2360          | 5.74            | 2003             | pincon, pinalb                               | 3               | 6                | 2                      |
| Fishhook Pond                     | 44.146    | 114.951    | 2360          | 5.27            | 2003             | pincon, pinalb                               | 3               | 6                | 2                      |
| Dutch Lake                        | 44.143    | 114.959    | 2080          | 1.50            | 2002             | pincon                                       | 3               | 6                | 2                      |
| Cape Horn                         | 44.345    | 115.166    | 2129          | 3.25            | 2007             | pincon,psemen                                | 3               | 6                | 2                      |
| Cape Horn II                      | 44.413    | 115.131    | 1994          | 4.71            | 2006             | pincon                                       | 3               | 6                | 2                      |
| Elk Lake                          | 44.404    | 115.136    | 2011          | 4.16            | 2006             | pincon                                       | 3               | 6                | 2                      |
| KES Lake                          | 44.413    | 115.038    | 2165          | 4.00            | 2006             | pincon                                       | 3               | 6                | 2                      |
| F-82                              | 44.373    | 115.038    | 2082          | 4.50            | 2007             | pincon                                       | 3               | 6                | 2                      |
| Bayhorse                          | 44.398    | 115.074    | 2082          | 3.77            | 2006             | pincon                                       | 3               | 6                | 2                      |
|                                   | 44.412    | 114.402    | 2617          | 6.69            | 2007             | pinalb, pincon                               | 3               | 6                | 2                      |

<sub>1</sub> Species are abbreviated as: pincon = *Pinus contorta*, pinalb = *Pinus albicaulis*, psemen = *Pseudotsuga menziesii*, abilas = *Abies lasiocarpa*

Table 2.2. Insect parts identified by Dr. Allan Ashworth (see appendix A for more information)

| Lake   | Core ID | Sediment   |                                         |
|--------|---------|------------|-----------------------------------------|
|        |         | Depth (cm) | Identified as                           |
| Decker | A       | 0-2        | possibly Diptera – head capsule         |
| Decker | A       | 2-4        | pronotum Saldid bug (Homoptera)         |
| Decker | A       | 2-4        | probably Diptera – head capsule         |
| Decker | A       | 2-4        | Diptera – head capsule                  |
| Decker | A       | 2-4        | Homoptera – part of head capsule        |
| Decker | A       | 2-4        | misc. sternite                          |
| Decker | A       | 2-4        | possibly Diptera – head capsule         |
| Decker | A       | 2-4        | possibly Diptera – head capsule         |
| Decker | A       | 2-4        | misc. chitin                            |
| Decker | A       | 2-4        | misc. chitin                            |
| Decker | A       | 2-4        | Diptera – head capsule                  |
| Decker | A       | 2-4        | misc. chitin                            |
| Decker | A       | 2-4        | misc chitin                             |
| Decker | A       | 4-6        | misc. chitin                            |
|        |         |            | Diptera – depending on scale Possibly a |
| Decker | A       | 4-6        | chironomid                              |
| Decker | A       | 4-6        | misc. chitin                            |
| Decker | A       | 4-6        | misc. chitin                            |
| Decker | A       | 4-6        | sternite Coleoptera – indet.            |
| Decker | A       | 4-6        | head capsule Possibly Diptera           |
| Decker | A       | 4-6        | sternite Coleoptera – indet family      |
| Decker | A       | 4-6        | sternite Coleoptera – indet family      |
| Decker | A       | 4-6        | sternite Coleoptera – indet family      |
| Decker | A       | 4-6        | sternite Coleoptera – indet family      |

The *Coleoptera* remains were distinctive enough that they were used as the basis for further insect identification. Ryan Bracewell, research assistant with the USDA bark beetle research team in Logan, Utah, helped to identify the remaining fragments that Dr. Ashworth was unable to identify. He mentioned that identifying insects based on fragments is nearly impossible as most diagnostic characteristics are missing (R. Bracewell, written communication, 2008, appendix A). The insect parts identified by Ryan Bracewell were also examined by Donald Bright, a bark beetle expert at Colorado

State University Department of Bioagricultural Sciences and Pest Management. Dr. Bright, echoed the response of Ryan Bracewell, suggesting that based on the fragments isolated from the sediment, species identification was not likely (D. Bright, written communication).

The forests at Martha Lake, like at Decker had very high mortality (70%). ADS data indicate that the area was first affected by mountain pine beetle outbreak in 2004 (available online: <http://www.fs.fed.us/foresthealth/technology/gis.shtml#ADS>).

Sediment cores were taken at Martha Lake from 10 different locations (Fig. 2.2). These included coring locations along the northern and southern shores and at the eastern margin, which based on the lake's orientation, we assumed to be the downwind area. Downwind areas were deemed important as we postulated that insect parts may float on the surface, be blown down wind, and eventually accumulate in the littoral zones near the downwind shore. Four insect parts were isolated from four different cores at sediment depths of 0 – 2 (2x), 2 – 4 and 4 – 6 cm below the sediment surface (Table 2.3; Fig. 2.2). Based on the data from Decker and Hidden lakes, it was determined that there were no clear patterns to indicate where insect parts would be likely to accumulate within a lake. Consequently, other lakes were sampled at 2 cm intervals to a depth of 6 cm from three locations: the area of deepest water and two littoral areas.

Table 2.3. Number of insect parts found at each depth from cores taken at Decker and Martha lakes. Asterisk at Decker core A depth 4-6 cm indicates location where Coleoptera remains were found (5 of 10 insect parts were possibly Coleoptera).

### Decker Lake

| Core | # Insect Parts 0-2cm | # Insect Parts 2-4cm | # Insect Parts 4-6cm | # Insect Parts 6-8cm |
|------|----------------------|----------------------|----------------------|----------------------|
| A    | 1                    | 12                   | 10*                  | 0                    |
| B    | 0                    | 0                    | 0                    | 0                    |
| C    | 0                    | 0                    | 0                    | 0                    |
| D    | 0                    | 0                    | 0                    | 0                    |
| E    | 2                    | 1                    | 1                    | 0                    |
| F    | 1                    | 0                    | 3                    | 0                    |
| G    | 0                    | 0                    | 0                    | 0                    |
| H    | 1                    | 0                    | 0                    | 0                    |
| I    | 2                    | 0                    | 0                    | 0                    |

### Martha Lake

| Core | # Insect Parts 0-2cm | # Insect Parts 2-4cm | # Insect Parts 4-6cm |
|------|----------------------|----------------------|----------------------|
| A    | 1                    | 1                    | 0                    |
| B    | 0                    | 0                    | 0                    |
| C    | 0                    | 0                    | 0                    |
| D    | 1                    | 0                    | 0                    |
| E    | 0                    | 0                    | 0                    |
| F    | 0                    | 0                    | 0                    |
| G    | 0                    | 0                    | 0                    |
| H    | 0                    | 0                    | 0                    |
| I    | 0                    | 0                    | 0                    |
| J    | 0                    | 0                    | 1                    |

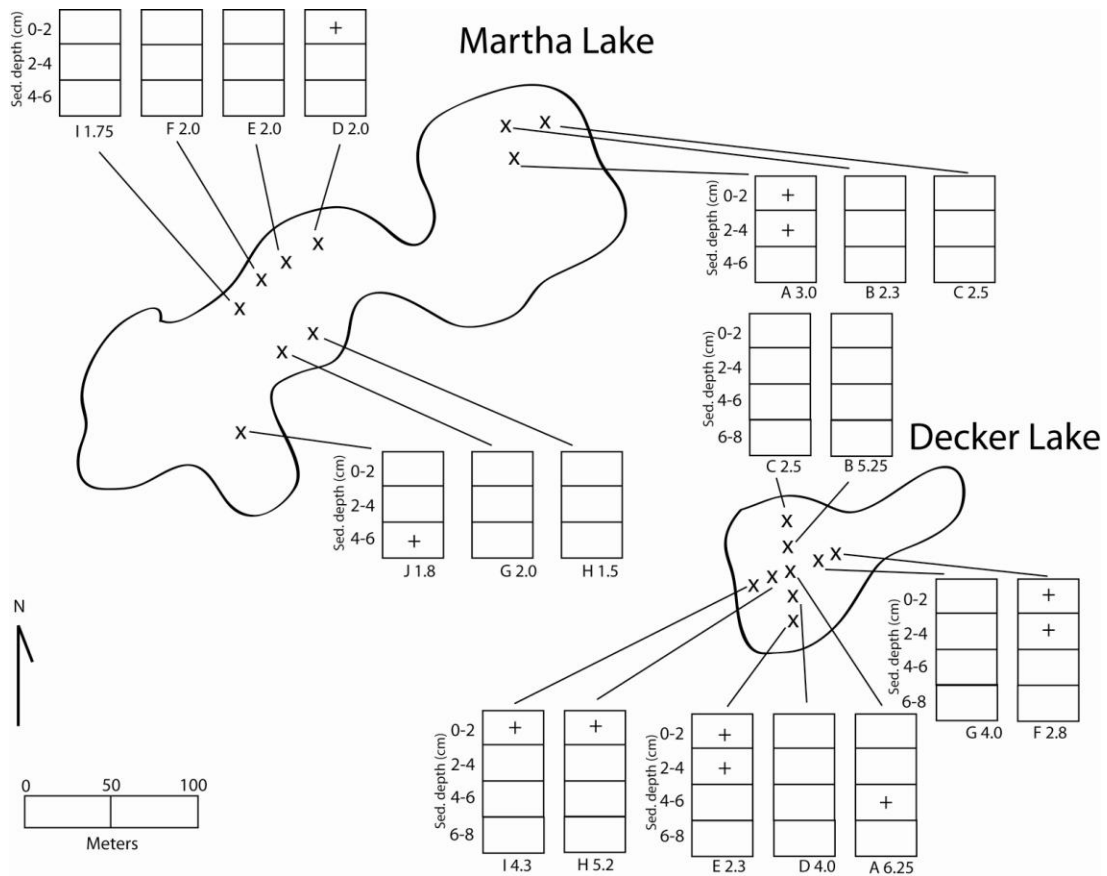


Figure 2.2. Map showing Martha and Decker lakes as well as sampling locations (x marks). Boxes depict the results from analyzing the cores at two-cm intervals for insect remains. The occurrence of insect parts (represented with + marks) corresponding to sediment depth (listed on left side of boxes). The water depth (m) of each core is listed in meters at the base of each box along with a letter indicating core ID.

Sediment cores from 19 other lakes (Table 2.1; Fig. 2.1) were analyzed for insect parts. Anything resembling an insect part was removed, archived and photographed after processing the sediment as described in the methods sections of this chapter. A total of 58 cores was taken and 174 samples were processed for insect parts. From these 174 samples, 21 insect parts were removed, photographed and archived (Table 2.3).

Table 2.4. Sites analyzed for insect parts (not including Decker and Martha lakes), depths where insect parts were isolated and the number of insect parts isolated at each depth

| Lake Name          | # parts 0-2 | # parts 2-4 | # parts 4-6 |
|--------------------|-------------|-------------|-------------|
| Sawtooth City Lake | 0           | 0           | 1           |
| Hellroaring Lake   | 2           | 1           | 1           |
| Goat Meadow Lake   | 0           | 0           | 0           |
| Marshall Lake      | 1           | 0           | 1           |
| Hidden Lake        | 0           | 0           | 0           |
| Decker Lake 2      | 0           | 1           | 0           |
| Cabin Creek 1      | 0           | 1           | 1           |
| Cabin Creek 2      | 0           | 0           | 0           |
| Running Cow Pond   | 0           | 0           | 0           |
| Big Bench Lake     | 0           | 1           | 1           |
| Lil Bench Lake     | 0           | 0           | 0           |
| Fishhook Pond      | 0           | 1           | 1           |
| Dutch Lake         | 0           | 2           | 0           |
| Cape Horn Lake     | 0           | 0           | 0           |
| Cape Horn II Lake  | 0           | 0           | 1           |
| Elk Lake           | 0           | 1           | 1           |
| KES Lake           | 0           | 0           | 0           |
| F-82 Lake          | 0           | 0           | 0           |
| Bayhorse Lake      | 1           | 1           | 1           |

### Discussion

At Decker Lake, 34 insect parts were removed from the sediment cores, and only five samples were identified as Coleoptera. The fragmentary nature of the insect remains prohibited identification below the level of order. The samples that were identified as Coleoptera came from the same sample (core A: depth 4-6cm) located at a deep-water point in the lake. Based on sedimentation rate at the site, this depth is interpolated to represent an age of approximately AD 1996 – 1980 (Chapter 3 of this

thesis; Table 3.1). This suggests that these insect remains were not deposited during the recent severe outbreak but from an earlier Coleoptera deposition event, possibly in the 1980s or 1990s.

During initial lab work, I removed anything that vaguely resembled an insect part. After sending these initial samples to Dr. Ashworth, it became apparent that the majority of the insect detritus present in the sediments came from flies and midges. After looking more closely at the samples positively identified as Coleoptera and from reference samples of mountain pine beetle, I was better able to identify possible mountain pine beetle fragments from other insect remains. This explains why the samples from Decker Lake yielded higher numbers of insect parts than at the other sites (Table 2.3; Fig. 2.2).

At Martha Lake, four insect parts were recovered from the sediment samples. These four insect parts came from sediment depths of 0 – 2 (two parts), 2 – 4 and 4 – 6 cm below the sediment surface. The insect parts were found in locations that suggest no particular pattern of deposition. The watershed of Martha Lake had very high forest mortality (70%), and the samples were taken in many locations to locate an ideal sampling location in relation to wind directions that could be applied to other sites.

The other 19 sites that were sampled also yielded very few insect remains. Collectively, all 19 sites yielded only three insect parts in the upper 2 cm of sediments. Deeper in the cores (2 – 4 cm sediment depth), nine insect parts were present at Hellroaring, Decker 2, Cabin Creek 1, Fishhook, Dutch, Elk and Bayhorse lakes (Table

1.3). Based on age determinations from other sites in the area (Chapter 2 this thesis; Table 2.1), depths between 2 – 4cm are estimated to represent sediments deposited in the 1990s and 1980s, before the widespread outbreaks observed today. Regardless of the identity of these parts, their interpolated ages suggest that they have nothing to do with the current outbreak taking place in and around the lakes.

Deeper in the cores, sediments from 4 – 6 cm depth yielded nine insect parts at Sawtooth City, Hellroaring, Cabin Creek, Big Bench, Fishhook, Cape Horn II, Elk and Bayhorse lakes. The interpolated age for these samples is between 1950 and 1960 (Chapter 3 this thesis; Table 3.1). Once again based on this age range, there is no relation between the current outbreak and the occurrence of insect fragments. These insect remains may be a signal from a previous deposition event from the mid 19<sup>th</sup> century.

Decker and Martha lakes are situated in forests heavily influenced by mountain pine beetle. These sites were sampled two years after outbreaks were first observed in the forests surrounding the lakes (Table 2.1). Considering that their surface sediments (0 – 2 and 2 – 4 cm below sediment surface) yielded so few insect parts, the data suggest that remains of mountain pine beetle are very rare in lakes, even in the years immediately following an outbreak. Decker and Martha lakes were sampled in more locations than other sites, and still no apparent patterns of high versus low insect accumulation were noted in the data.

The other sites (Table 2.3) support the findings from initial analysis at Decker and Martha lakes. The number of insect parts found in these sediments was very low and no lake showed an abundance of insect parts. These sites covered a broad range of locations, elevations, forest types (Table 2.1), and initial infestation dates (Table 2.3). Since so few insect parts were found, there does not appear to be any pattern of insect part occurrence as a function of environmental variables (i.e. elevation, forest type, infestation date or location). Once again, these data further support the findings from Decker and Martha lakes. It appears that in the years following an outbreak, few mountain pine beetle remains accumulate in the sediments of lakes, even when the surrounding forests are heavily infested.

Several scenarios may explain why mountain pine beetle parts were not found in abundance in the lakes of the Sawtooth Mountains. Sediment sample sizes were very small ( $10\text{ cm}^3$ ) and analyzing a larger volume of sediment may have yielded better results. Other studies looking at paleo-insect remains have used very large sample sizes as compared to this study, which analyzed  $10\text{ cm}^3$  samples. Marra and Leschen (2004) investigated 20 kg samples from fluvial deposits in New Zealand to reconstruct climate data from insect fossils. Samples of this size are several orders of magnitude larger than the volume analyzed in this study.

It is also possible that more time is needed following outbreaks before insects become incorporated in lake sediments. At all of the lakes sampled, less than ten years had passed between the time of initial infestation and the sediment sampling. It is

possible that mountain pine beetle remains had not yet been incorporated into the lake sediment. Of all sites visited, trees infested by mountain pine beetle were still standing and had their bark intact. It is a distinct possibility that more time will be required for trees to decompose and for the imbedded insects to be incorporated into lake sediments.

It is unlikely that decomposition is occurring within lake sediment systems or that organisms within the lake are having a significant impact on the presence of mountain pine beetle fragments within the lakes. Wyatt Cross, freshwater ecosystem specialist and Assistant Professor in the Department of Ecology at Montana State University, suggested that if large amounts of insects were getting washing into lakes, they would probably show up in sediment samples. He also mentioned that exoskeletons of beetle are very resistant to consumption and digestion suggesting that they would not likely decompose in a lake ecosystem (W. Cross, written communication; Appendix B??). Brunelle et al. (2007) found *Dendroctonus* fossils preserved in lake sediments for at least 8000 years, suggesting that they are resistant to decomposition in a lake-sediment sequence.

The results of this study suggest little evidence of *Dendroctonus* remains in lakes in the years following an outbreak. Further study of present-day processes in forest stands infested by mountain pine beetle are needed to determine if lake-sediment records can be used to reconstruct historical records of pine beetle infestation.

### Conclusions

Lake-sediment records from the Sawtooth Mountains, ID were used to evaluate their potential to preserve evidence of outbreaks of mountain pine beetle. The Sawtooth Mountains have been heavily infested by mountain pine beetle in the last decade and provide an ideal location to test this question. The results of this study indicate that very few insect remains were present in the upper centimeters of lake sediments in the years following an outbreak. The data suggest little relation between the occurrence of insect parts in lake sediments and mountain pine beetle infestation in a corresponding watershed. More time may be necessary for insect remains to be incorporated into lake-sediment sequences.

Other processes may be operating that rapidly decompose mountain pine beetle fragments upon entering a watershed although considering the abundance of other insect remains, such as from flies and aquatic insects, this seems unlikely. Past studies have used mountain pine beetle remains in lake sediments as a proxy of past infestation (Brunelle et al., 2007). Brunelle et al. (2007) found occurrence of *Dendroctonus* fossils at distinct points in the early Holocene (ca. 7000 – 8000 cal yr BP) which they associated with cooler, wetter conditions. The results of my study imply that caution should be used in interpreting the occurrence of mountain pine beetle fragments in lake sediments as a proxy for past infestations. Further investigation is needed to better understand the processes that influence the preservation of mountain pine beetle

remains in lake-sediment records before accurate and interpretable records of past mountain pine beetle infestation are possible.

This study proved to be an interesting pilot study and could be expanded in the future. Larger samples of sediment should be analyzed possibly at volumes as large as 1 m<sup>3</sup>. Samples of this magnitude could be collected from the shallow, marginal areas of lakes. Another method might involve collecting samples from peat bogs. Samples of larger size have proven to yield insect fossils in other fossil insect studies and may better record insect outbreaks. It is also important to monitor surrounding forest stands to determine at which point trees fall and shed their bark, possibly releasing insect fragments into the lake sediment system.

### References Cited

- Amman, G. D. (1982). Characteristics of mountain pine beetles reared in four pine hosts. *Environ. Entomol* 11, 590-593.
- Amman, G. D., and Cole, W. E. (1983). Mountain pine beetle dynamics in lodgepole pine forests. Part II: population dynamics. USDA For. Serv. Gen. Tech. Rep. INT-145 59.
- Brunelle, A., Rehfeldt, G. E., Bentz, B., and Munson, A. S. (2007). Holocene records of *Dendroctonus* bark beetles in high elevation pine forests of Idaho and Montana, USA. *Forest Ecology and Management*.
- Carroll, A. L., Taylor, S.W., Régnière, J., Safranyik, L. (2003). Effects of Climate Change on Range Expansion by the Mountain Pine Beetle in British Columbia. In "Mountain Pine Beetle Symposium: Challenges and Solutions." (T. L. Shore, Brooks, J.E., and Stone, J.E., Ed.), pp. 298, Kelowna, British Columbia.
- Hicke, J. A., Logan, J.A., Powell, J., and Ojima, D.S. (2006). Changing temperature influence suitability for modeled mountain pine beetle (*Dendroctonus ponderosae*) outbreaks in the western United States. *Journal of Geophysical Research* 111, 1-12.
- IPCC, C. C. (2007). The Physical Science Basis-Summary for Policymakers. R. Alley et al., 18pp,(2007)(<http://ipcc-wg1.ucar.edu/>).
- Logan, J.A., Bolstad, P.V., Bentz, B.J., and Perkins, D.L., (1995). Assessing the effects of changing climate on mountain pine beetle dynamics. Pp. 92-105 In Tinus, R.W. (ed.) *Proceedings, Interior west global climate workshop*. USDA-Forest Service GTR-RM-262. Fort Collins, CO.
- Logan, J.A., and Bentz, B.J., (1999). Model analysis of mountain pine beetle seasonality. *Environmental Entomology* (Forum Article) 28: 924-934.
- Logan, J. A., and Powell, J.A. (2001). Ghost Forests, Global Warming, and the Mountain Pine Beetle (Coleoptera: Scolytidae). *American Entomologist* Fall 2001, 160-172.
- Marra, M., and Leschen, R.A.B. (2004). Late Quaternary paleoecology from fossil beetle communities in the Awatere Valley, South Island, New Zealand. *Journal of Biogeography* 31, 571-586.
- Mattson, D. J., and Reinhart, D. P. (1997). Excavation of red squirrel middens by grizzly bears in the whitebark pine zone. *Journal of Applied Ecology* 34, 926-940.

Romme, W.H., Clement, J., Hicke, J., Kulakowski, D., MacDonald, L.H., Schoennagel, T.L., and Veblen, T.T. (2008). Recent Forest Insect Outbreaks and Fire Risk in Colorado Forests: A Brief Synthesis of Relevant Research. Available Online: [www.cfri.colostate.edu/docs/cfri\\_insect.pdf](http://www.cfri.colostate.edu/docs/cfri_insect.pdf)

## CHAPTER 3

COMPARING LATE HOLOCENE FIRE HISTORIES  
FROM THREE LAKE SEDIMENT RECORDS  
IN THE SAWTOOH MOUNTAINS,  
IDAHOIntroduction

Fire is a natural form of disturbance in the Rocky Mountain West shaping forest composition and aiding in nutrient cycling (Boerner, 1982). Although fire is an integral part of many ecosystems, the frequency and severity of wildfires in the western United States have increased in recent decades as a result of human activities and climate warming (Veblen et al., 2000; Westerling et al., 2006). For example, Veblen et al. (2000) found that fuel buildup resulting from management practices increased the occurrence of large-scale stand-replacing fire events in the Colorado Front Range. Westerling et al. (2006) attributed warmer temperatures and an earlier spring snowmelt to more frequent wildfires and a longer fire season in the western United States. Because annual costs of fire mitigation regularly exceed \$1 billion and wildfires have burned over 4 million hectares during recent fire seasons (NIFC, 2008), it is important to have a better understanding of the natural fire regime prior to the influence of Euro-Americans. This information can help assess the role of climate change in shaping the present conditions and the degree to which forests have been altered by management practices including fire suppression.

Holocene records of vegetation and fire from the Rocky Mountains are derived primarily from studies of fossil pollen (Whitlock, 1993; Brunelle et al., 2005), plant macrofossils (Lyford et al., 2003), sediment charcoal (Power et al., 2006) and tree rings (Biondi and Perkins, 1999; Pederson et al., 2004). Past fire activity, reconstructed from fossil charcoal in lake sediments, as well as fire-scarred tree rings, has been shown to respond to climate variations occurring on decadal to millennial time scales. For example, on decadal time scales, tree-ring studies record changes in moisture availability (Biondi and Perkins, 1999). On centennial time scales, tree-ring and charcoal data indicate periods of high and low fire activity as a result of drier-than-present conditions during the Medieval Climate Anomaly (1050 – 650 cal yr BP; Pierce et al., 2004) and cold, effectively wetter conditions in the Little Ice Age (750 – -50 cal yr BP; Meyer and Pierce, 2003). On millennial time scales, warmer drier conditions during the early-Holocene summer insolation maximum increased fire frequency across the western US (Millsbaugh et al., 2000; Hallett and Hills, 2006; Whitlock et al., 2008).

Instrumental records of temperature show a global increase of 0.7°C in the last century (IPCC, 2007). Warmer summer temperatures have led to longer wildfire season and subsequent higher fire activity in recent decades (Westerling et al., 2006). Future climate projections, derived from general circulation models, indicate that portions of the Northern Rockies could experience an increase in mean annual temperatures of 3.2°C by 2070 and 6°C by the end of the century (Coupled Model Intercomparison Project Data (CMIP3), 2007).

To better understand the environmental history of central Idaho, a study was undertaken to investigate the fire history of the last 2000 years in the Sawtooth Mountains of central Idaho. Sediment cores were collected from three small lakes in close proximity (<40 km apart) and at similar elevation (within 45m elevation of one another). The lakes were located in closed forests dominated by lodgepole pine (*Pinus contorta*). Climate is and probably has been similar among the sites over the last two millennia, and if climate alone has been driving the fire regimes, then the sites should have similar fire histories. If the fire records are dissimilar, it suggests non-climate controls, such as variations in fuel conditions or human activity, including fire suppression policies and Native American burning. My objectives were to answer the following questions about fire history of the last 2000 years in the Sawtooth Mountains: 1) how has the occurrence of fire varied during the last 2000 years, and 2) do the fire records at different sites suggest similar fire patterns that imply a shared response to climate change?

The lakes are located on the northeastern and northern flank of the Sawtooth Mountains (Fig. 3.1). None of the sites had inflowing or outflowing streams. Cape Horn II Lake (44.404° N, 115.136°W, 2126 m, 1.3 ha, 4.6 m) is on the north side of the Sawtooth Mountains, in valley underlain by late-Pleistocene outwash (Fisher et al., 1992). The surrounding forest is composed of *Pinus contorta*, although some *Pseudotsuga menziesii* (Douglas-fir) grows on the eastern shore. *Nuphar polysepala* (yellow cow-lily) covers the eastern margin of the lake.

Hidden Lake (44.293° N, 115.115°W, 2142 m, 2.1 ha, 5.3 m) lies just to the north of the Sawtooth front in a kettle depression underlain by late-Pleistocene till (Fisher et al., 1992). The forest surrounding Hidden Lake is dominated by *Pinus contorta* with scattered trees of *Pseudotsuga menziesii*.

Decker Lake (44.069° N, 115.134°W, 2167 m, 0.89 ha, 6.3 m) is located just northeast of the Sawtooth Mountains on late-Pleistocene glacial till (Fisher et al., 1992). The forest that surrounds Decker Lake is dominated by *Pinus contorta* and also includes scattered *Pseudotsuga menziesii* on the northern margin of the lake. *Nuphar polysepala* covers the eastern, shallow margin of the lake and along the littoral zone.

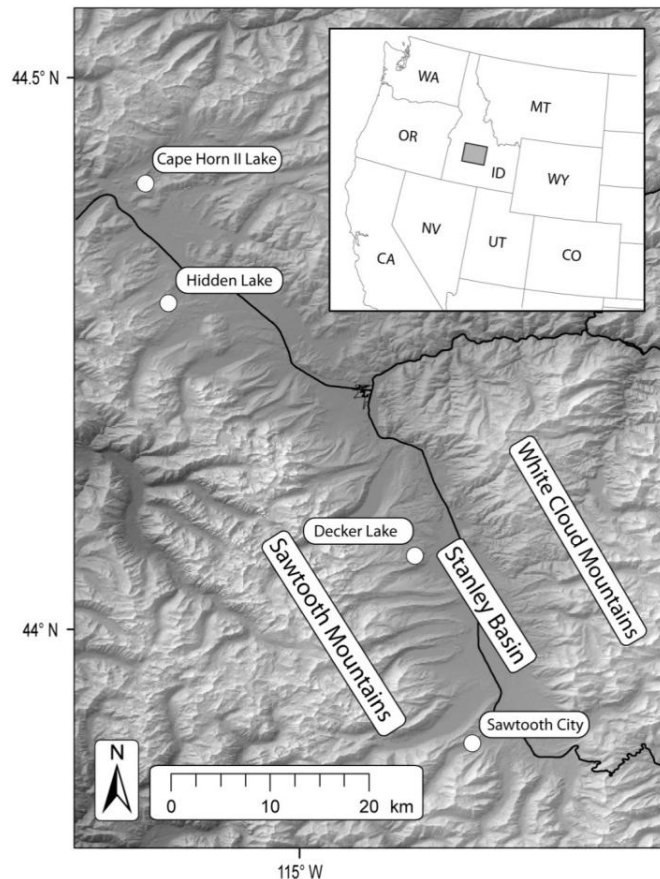


Figure 3.1. Map of study region showing location of study sites and other geographic features mentioned in text.

### Methods

Short cores were retrieved from the deepest water depth at Decker, Hidden and Cape Horn II lakes using a polycarbonate tube fitted with a piston corer to recover the mud-water interface intact. Cores were extruded at 1-cm intervals at Decker Lake and at 0.5-cm intervals at Cape Horn II and Hidden lakes and sampled into whirlpak bags. Samples were refrigerated upon arrival at the Montana State University Paleoecology Lab.

Loss-on-ignition is a method used to determine the organic and inorganic content of the lake and thereby estimate lake productivity (Dean, 1974). Samples of 2 cm<sup>3</sup> volume were analyzed at 1-cm intervals from Decker Lake and at 0.5-cm intervals from Hidden and Cape Horn II lakes. Sampling resolution differed between sites because of differences in sampling equipment used. When Decker Lake was initially sampled, the finest resolution attainable with the equipment was 1cm increments while equipment used at other sites allowed for resolution of .5cm. Samples were dried at 90°C to remove the water content and estimate sediment bulk density. Samples were ignited for 2 hours at 550°C, burning off organics, and then at 900°C for 2 hours to burn off carbonates. By measuring the weight loss after each step, it was possible to calculate organic content and carbonate content (Dean, 1974).

In order to reconstruct the fire history, 1 cm<sup>3</sup> samples were taken at 1-cm intervals at Decker Lake and at 0.5-cm intervals at Cape Horn II and Hidden lakes for charcoal analysis. Samples were soaked in a solution of 5% sodium hexametaphosphate

and 6% bleach for 24 hours and rinsed through nested, 125 and 250  $\mu\text{m}$  mesh sieves. The residues were placed in Petri dishes and tallied under a stereoscope at magnifications of 40-80X (Whitlock and Larsen, 2001).

A chronology was established from a series of  $^{210}\text{Pb}$  ages as well as a radiocarbon age at the base of each core. The radiocarbon ages were converted to calendar years using CALIB version 5.0.1 (Stuiver and Reimer, 1993) and by convention, 0 cal yr BP is assigned to AD 1950. Age depth models were developed for all sites with a smoothing spline procedure using software developed by P. Higuera (<http://www.montana.edu/phiguera/software/software.html>). The procedure estimated 95% confidence intervals through the course of 5000 Monte Carlo simulations. In each of the 5000 trials, splines were fit to the probability density function obtained from a calibration performed using CALIB 5.1.0 software (Stuiver and Reimer, 1993).

Charcoal counts were divided by sample volume to calculate charcoal concentration (particles  $\text{cm}^{-3}$ ), and charcoal accumulation rates (CHAR, particles  $\text{cm}^{-2} \text{yr}^{-1}$ ) were calculated by multiplying charcoal concentration by sediment accumulation rate ( $\text{cm yr}^{-1}$ ). Charcoal data were converted to evenly spaced time intervals by interpolating the data to the median deposition time for each lake ( $\text{yr cm}^{-1}$ ).

CHAR data are generally decomposed into two components, a slowly varying background component and a high frequency peaks component (Clark et al., 1996; Long et al., 1998). Background charcoal (BCHAR) has been interpreted as representing

regional fire or as secondary charcoal washed in from the surrounding watershed and littoral zone (Clark and Royal, 1996; Whitlock and Millspaugh, 1996). Positive deviations above background charcoal are termed the peaks component, and interpreted as fire episodes, i.e., one or more fires occurring during the particular sampling interval.

Decomposition of these records was accomplished with the software program CharAnalysis ([www.montana.edu/phiguera/software/software.html](http://www.montana.edu/phiguera/software/software.html); Higuera et al., 2008). CharAnalysis is a freeware program used to analyze charcoal records, detect charcoal peaks, and reconstruct fire history at a site-specific scale. BCHAR was modeled using a LOWESS smoother robust to outliers. Window widths between 500 and 1000 years were considered to determine BCHAR, and 500 years was ultimately selected as it maximized the signal-to-noise index. Charcoal peaks were identified using a Gaussian mixture model, similar to that of Gavin et al. (2006). The 95 percentile of the distribution was selected as a threshold separating significant charcoal peaks from a noise component. Because overall charcoal production in the area surrounding a lake may have changed over time, the Gaussian mixture model was applied to each sample and the samples 500 years on each side of the sample. Identified peaks were further screened by a minimum count test, which checks for peak significance by analyzing the minimum charcoal value within 75 years before an identified peak. If the probability of this minimum value coming from the same two-sided Poisson distribution as the identified peak was less than  $\alpha$  (in this case .05), then the peak was deemed significant.

Fire frequency was calculated by summing the total number of peaks within a moving 1000-yr window. All figures were plotted in the statistical environment R (R core development team, 2008).

### Results

A 97-cm-long core from Cape Horn II Lake was composed of fine detritus gyttja. A total of 21 dates (Table 3.1) was analyzed for  $^{210}\text{Pb}$  dating by Flett Research Ltd. of Winnipeg, Manitoba. A radiocarbon date from a depth of 94.5-97.5 cm yielded an age of  $1269 \pm 98$   $^{14}\text{C}$  yr BP (1183 cal yr BP; AA70042). The two sets of dates were used to reconstruct a chronology (Fig. 3.2). The median sedimentation rate at was  $8 \text{ years cm}^{-1}$ .

At Cape Horn II Lake, organic content varied between 20 and 55%, and the carbonate content fluctuated between 1 and 30% (Fig. 3.3). Organic content was minimal in the lower part of the core with values  $\sim 30\%$ , and increased to  $\sim 40\%$  above 40 cm depth. Carbonate content was low below 80 cm depth and increased gradually towards the top of the core. BCHAR varied between 0 and  $1.5 \text{ particles cm}^{-2} \text{ yr}^{-1}$  throughout the record. Values were high at  $\sim 1000$  cal yr BP with values of  $\sim 1 \text{ particle cm}^{-2} \text{ yr}^{-1}$  and decreased to a low at  $\sim 200$  cal yr BP ( $\sim 0.75 \text{ particle cm}^{-2} \text{ yr}^{-1}$ ). In the last 200 years, BCHAR increased to  $\sim 1.5 \text{ particles cm}^{-2} \text{ yr}^{-1}$ . Charcoal peaks identified 10 fire episodes at 159 – 167 cal yr BP (AD 1791 – 1783), 223 – 231 cal yr BP (AD 1727 – 1719), 287 – 295 cal yr BP (AD 1663 – 1655), 375 – 383 cal yr BP (AD 1575 – 1567), 519 – 527 cal yr BP (AD 1431 – 1423), 839 – 847 cal yr BP (AD 1111 – 1103), 911 – 919 cal yr BP (AD

1039 – 1031), 1047 – 1055 cal yr BP (AD 903 – 895), 1151 – 1159 cal yr BP (AD 799 – 791) and 1175 – 1183 cal yr BP (AD 775 – 767) (Fig. 3.4).

The Hidden Lake core was 84 cm long and composed of fine detritus gyttja. A total of 21 samples were analyzed for  $^{210}\text{Pb}$  analysis (Table 3.1). A radiocarbon date at 75 cm depth had an age of  $1078 \pm 61$   $^{14}\text{C}$  yr BP (996 cal yr BP; AA70027). The  $^{210}\text{Pb}$  dates were used along with the calibrated radiocarbon date to develop a chronology for the core (Fig. 3.2). The median sedimentation rate was  $9 \text{ years cm}^{-1}$ .

Organic content varied between 70 and 30 % at Hidden Lake and carbonate values were between 0 and 20% (figure 3.3). Organic content was ~25% below 30 cm depth and values of ~40% were reached near the top of the core. Carbonate values were low in the lower portion of the core and increased markedly above 15 cm depth to values of ~20%. BCHAR was  $\sim 0.6 \text{ particles cm}^{-2} \text{ yr}^{-1}$  between 1200 and 600 cal yr BP, decreased to  $\sim 0.3 \text{ particles cm}^{-2} \text{ yr}^{-1}$  at 350 cal yr BP and increased to  $\sim 0.9 \text{ particles cm}^{-2} \text{ yr}^{-1}$  in the last 100 years (Fig. 2.4). Significant charcoal peaks were identified at 97 – 106 cal yr BP (AD 1853 – 1844), 268 – 287 cal yr BP (AD 1682 – 1663), 475 – 484 cal yr BP (AD 1475 – 1466), 547 – 556 cal yr BP (AD 1403 – 1394), 664 – 673 cal yr BP (AD 1286 – 1277), 727 – 736 cal yr BP (AD 1223 – 1214), 1006 – 1015 cal yr BP (AD 944 – 935) and 1141 – 1150 cal yr BP (AD 809 – 800) (Fig. 3.4).

Table 3.1  $^{210}\text{Pb}$  activity and age determinations.

| Depth (cm)        | $^{210}\text{Pb}$ dpm $\text{g}^{-1}$ | Age (cal yr BP) | Standard Error (yrs) |
|-------------------|---------------------------------------|-----------------|----------------------|
| Cape Horn II Lake |                                       |                 |                      |
| 0                 | 89.322                                | -57             | 1.938                |
| 1                 | 86.063                                | -44             | 2.249                |
| 2                 | 78.990                                | -34             | 1.473                |
| 3                 | 77.855                                | -29             | 1.569                |
| 4                 | 79.008                                | -24             | 1.557                |
| 5                 | 81.522                                | -20             | 1.532                |
| 6                 | 84.527                                | -16             | 1.823                |
| 7                 | 78.826                                | -10             | 2.341                |
| 8                 | 84.588                                | -4              | 1.614                |
| 9                 | 83.674                                | 1               | 1.632                |
| 11                | 79.837                                | 12              | 1.359                |
| 13                | 68.576                                | 22              | 1.210                |
| 15                | 69.791                                | 31              | 1.123                |
| 19                | 61.347                                | 52              | 1.104                |
| 22                | 51.559                                | 74              | 0.986                |
| 25                | 36.567                                | 99              | 0.663                |
| 28                | 24.057                                | 125             | 0.838                |
| 32                | 16.312                                | 180             | 0.420                |
| 36                | 7.131                                 | 234             | 0.277                |
| 40                | 4.234                                 | 256             | 0.195                |
| 42                | 4.945                                 | 261             | 1.183                |
| Hidden Lake       |                                       |                 |                      |
| 0                 | 128.690                               | -56             | 0.500                |
| 1                 | 99.290                                | -55             | 0.500                |
| 2                 | 69.890                                | -55             | 0.500                |
| 3                 | 92.950                                | -54             | 0.500                |
| 4                 | 116.010                               | -53             | 0.500                |
| 5                 | 108.860                               | -51             | 0.500                |
| 6                 | 101.710                               | -49             | 0.500                |
| 7                 | 78.450                                | -44             | 0.500                |
| 8                 | 55.190                                | -41             | 0.500                |
| 9                 | 43.135                                | -39             | 0.500                |
| 10                | 31.080                                | -33             | 0.500                |
| 11                | 26.120                                | -18             | 0.500                |
| 12                | 21.160                                | -12             | 0.500                |
| 13                | 24.365                                | -7              | 0.500                |
| 14                | 27.570                                | -2              | 0.500                |
| 15                | 24.225                                | 5               | 0.500                |
| 16                | 20.880                                | 38              | 0.500                |
| 17                | 13.305                                | 96              | 0.500                |
| 18                | 5.730                                 | 153             | 0.500                |
| 19                | 4.670                                 | 183             | 0.500                |
| 20                | 3.610                                 | 158             | 0.500                |
| Decker Lake       |                                       |                 |                      |
| 0                 | 103.377                               | -56             | 1.218                |
| 1                 | 87.550                                | -51             | 0.904                |
| 2                 | 86.037                                | -46             | 1.025                |
| 3                 | 82.419                                | -40             | 0.793                |
| 5                 | 72.650                                | -27             | 0.765                |
| 7                 | 44.586                                | -10             | 0.590                |
| 9                 | 30.645                                | 7               | 0.533                |
| 13                | 13.904                                | 50              | 0.355                |
| 17                | 8.429                                 | 105             | 0.258                |
| 21                | 6.469                                 | 186             | 0.216                |
| 23                | 6.126                                 | 229             | 0.223                |

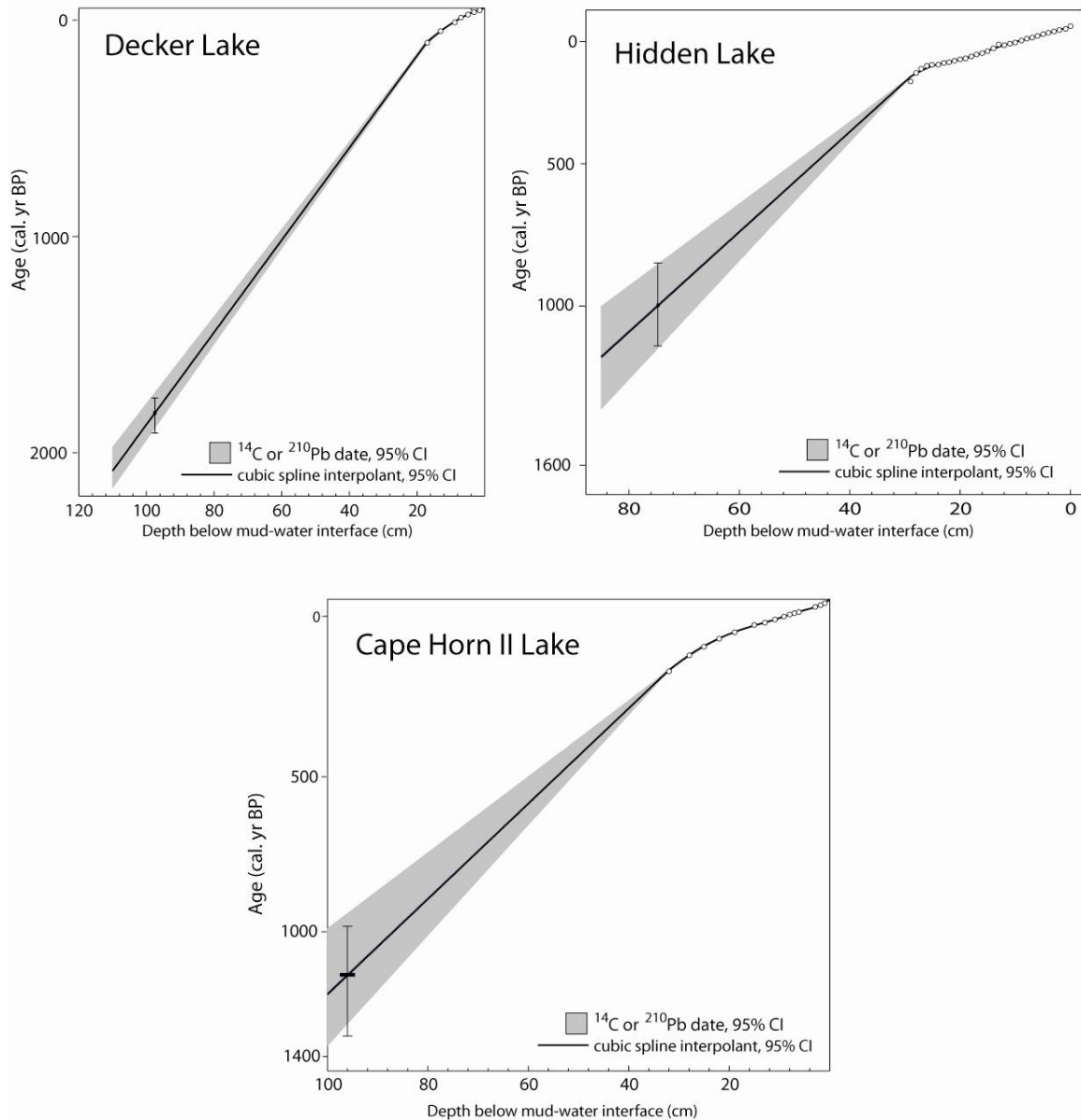


Figure 3.2. Calibrated age-depth curves for each site including  $^{14}\text{C}$  age and  $^{210}\text{Pb}$  age determinations.

At Decker Lake, a 101-cm-long core was recovered. The sediments were composed of fine detritus gyttja. Eleven  $^{210}\text{Pb}$  dates (table 3.2) were used to build a chronology for the upper portion of the core. One radiocarbon date obtained from a

depth of 98 cm yielded an age of  $1873 \pm 34$   $^{14}\text{C}$  yr BP (AA70026), which was calibrated as 1816 cal yr BP. The median sedimentation rate at Decker Lake was 21 years  $\text{cm}^{-1}$ .

Organic content of sediments from Decker Lake ranged from 15 to 55% and carbonate percentages did not exceed 5% (Fig. 3.3). Organic content was approximately 40-50% throughout the record with one point at 25 cm depth where values were ~15%. Carbonate content fluctuated slightly through the core. BCHAR was high between 1600 and 1500 cal yr BP with values of  $\sim 0.9$  particles  $\text{cm}^{-2} \text{yr}^{-1}$  and decreased to  $\sim 0.5$  particles  $\text{cm}^{-2} \text{yr}^{-1}$  at 900 – 800 cal yr BP. BCHAR rose to  $\sim 0.7$  particles  $\text{cm}^{-2} \text{yr}^{-1}$  at 600 – 500 cal yr BP, decreased to  $\sim 0.35$  particles  $\text{cm}^{-2} \text{yr}^{-1}$  near 300 cal yr BP and has been high in the last 100 cal years at  $\sim 0.9$  particles  $\text{cm}^{-2} \text{yr}^{-1}$  (Fig. 3.4). Eleven significant charcoal peaks were identified at 301 – 322 cal yr BP (AD 1649 – 1628), 469 – 490 cal yr BP (AD 1481 – 1460), 658 – 679 cal yr BP (AD 1292 – 1271), 868 – 889 cal yr BP (AD 1082 – 1061), 994 – 1015 cal yr BP (AD 956 – 935), 1036 – 1057 cal yr BP (AD 914 – 893), 1120 – 1141 cal yr BP (AD 830 – 809), 1288 – 1309 cal yr BP (AD 662 – 641), 1561 – 1582 cal yr BP (AD 389 – 368), 1645 – 1666 cal yr BP (AD 305 – 284) and 1834 – 1855 cal yr BP (AD 116 – 95) (Fig. 3.5).

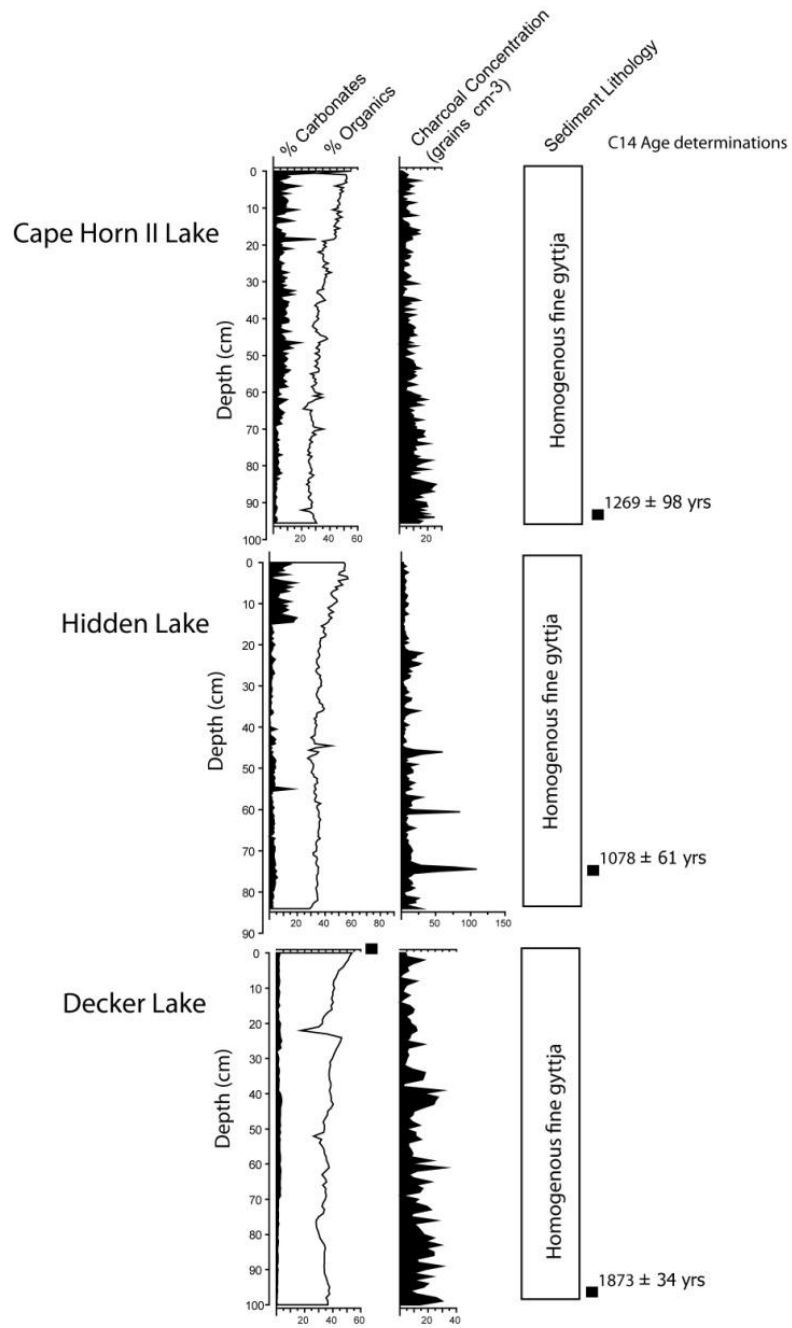


Figure 3.3 Carbonate and organic percentages, charcoal concentration (grains  $\text{cm}^{-3}$ ), lithology and age determinations from Cape Horn II, Hidden and Decker lakes.

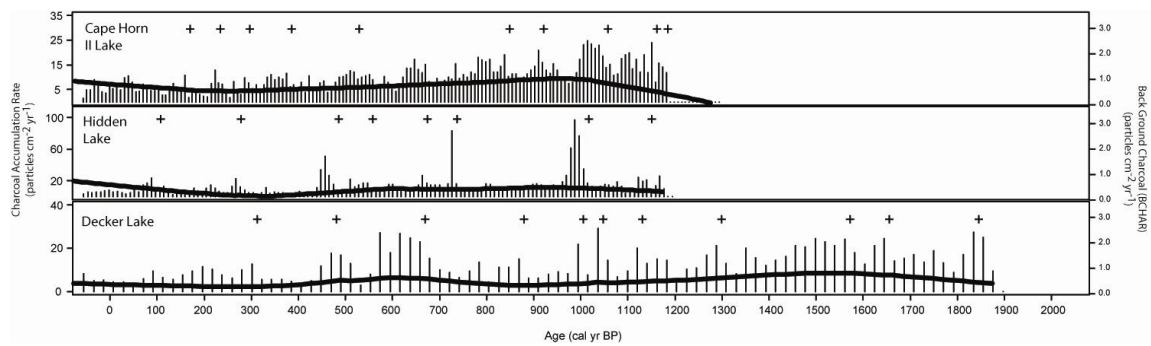


**Figure 3.4. Charcoal accumulation rates (black bars) background charcoal accumulation rates (BCHAR; smoothed lines), and identified fire events (+ signs) for all study sites.**

### Discussion

The charcoal records from Cape Horn II, Hidden and Decker lakes will be discussed in relation to regional records of vegetation, climate and human activity. The records will be described for three time intervals. The first time interval encompasses 2000 – 1200 cal yr BP (50 BP – AD 750) and is only described at Decker Lake. The second period spans 1200 – 600 cal yr BP (AD 750 - 1350) and encompasses the period, coinciding with the Medieval Climate Anomaly (MCA; 1050 – 650 cal yr BP; Pierce et al., 2004). This middle period will be examined independently to determine if the climate of the MCA helped explain the fire records from the three sites. The final period, 600 cal yr BP – present day (AD 1350 - 2006) will be examined for evidence of a response to climate changes during the Little Ice Age (LIA; 750 – 50 cal yr BP; Meyer and Pierce, 2003), as well as the activities of Euro-Americans, including early mining, ranching and recent management practices.

A pollen record from Decker Lake (C. Briles, unpublished data, 2008) provides a history of vegetation and fuel conditions against which to compare the fire records. The data indicate that modern forests composed of *Pinus contorta* were established by 4000 cal yr BP (Briles et al., in prep). Prior to the development of modern vegetation, forests contained more *Pseudotsuga menziesii*. The development of modern forest between 2400 and 4000 cal yr BP is well documented in other pollen records from northern Idaho and western Montana (Brunelle et al., 2005). For example, Brunelle et al. (2005) found that modern forests were established in the Clearwater Range of Idaho by 4000 cal yr BP as a result of cooler moister conditions than before. At Burnt Knob Lake in the Bitterroot Range of western Montana, modern forests were present at 2500 cal yr BP (Brunelle et al., 2005). Based on these studies, I assume that the present vegetation was established at the study sites in the Sawtooth Mountains before 2000 cal yr BP and that fuel composition was generally similar to present during the time span of this study.

Reconstructions of the Palmer Drought Severity Index (PDSI, Cook et al., 2004) disclose changes in drought severity over the last 2000 years. These data come from tree-ring reconstructions that have been interpolated across the landscape. PDSI data for the Sawtooth Mountains were downloaded from an interpolated grid point with coordinates of lat. 45°N, long 115° W. PDSI data indicate that conditions were cooler and wetter than at present between 1700 – 1150 cal yr BP (AD 250 – 800) (Fig. 3.6). After 1150 cal yr BP (AD 800) PDSI values suggest that conditions were drier and warmer

than at present; this period lasted approximately 400 years until 650 cal yr BP (1300 AD). After 675 cal yr BP (AD 1300), PDSI values remained near zero suggesting conditions have not been anomalous in either the positive or negative direction.

Humans may have helped shape the fire regime by both igniting and suppressing fires in the Sawtooth region. The earliest evidence of humans in the Stanley Basin dates to 10,000 yr BP near Redfish Lake (Galagher, 1975). About 75 km to the south, near Fairfield, ID, Clovis artifacts suggest humans were present as early as 11,000 – 12,000 yr BP (Butler, 1963). In other regions, it is assumed that the ability of early hunter-gatherers to set fires would have been strongly dependent on climate and fuel conditions (Barrett and Arno, 1982). Studies elsewhere in the Northern Rockies have attributed increased fire activity during the 17<sup>th</sup> and 18<sup>th</sup> centuries to Native Americans (Barrett and Arno, 1982), who may have used fire for a variety of purposes, including clearing travel corridors, managing hunting areas and improving pastures for horses, and food harvesting (Barrett and Arno, 1982).

Euro-Americans were present in the Stanley Basin after the 1820s, first trappers, then miners, and most recently ranchers (Idaho Historical Society, 1982). Significant settlement did not occur until mining booms late in the 19th century. In 1878 prospectors found signs of gold in the area indicating the potential for lucrative mining. By 1881, the mining town of Sawtooth City, near present-day Stanley, had a population of about 500 people (Miller, 1965) (Fig. 3.1). The mining boom was short-lived and

mining towns were abandoned by 1888 (Miller, 1965). If early mining activities did have an influence on fire regimes, it would be registered during the 1880s.

GIS data obtained from the USDA Forest Service illustrate patterns of burning in the Sawtooth National Forest (Fig 3.5) since 1950 (USDA Forest Service, Fire Data, 2007). These data illustrate the local fire regime and indicate three large events in the last two decades and several smaller events since 1950. The three large fires (Valley Road, Trapper Ridge and Trail Creek) burned between 33,217 and 155,500 acres in a variety of low and high elevation forests. These data do not assist in deciphering the nature of forest management and fire suppression, but do illustrate the location of fires in the region over the last 50 years.

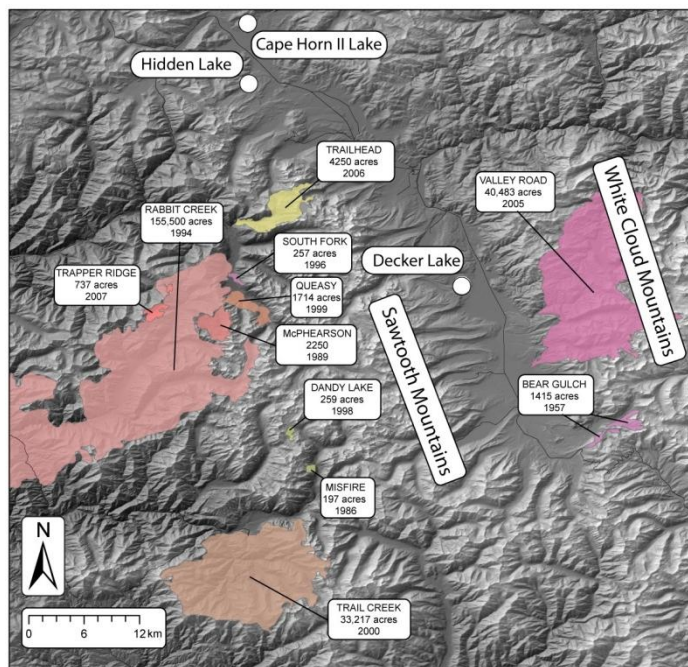


Figure 3.5. Fires in the Sawtooth National Forest since 1950 (shaded polygons). Study sites in text are indicated with white circles. Data in text boxes include the name of each fire, year and size of the burn (USDA Forest Service, Fire Data, 2008).

#### 2000-1200 cal yr BP (BC 50 – 750 AD)

At Decker Lake, four fire episodes occurred during this period, 1288 – 1309 cal yr BP (AD 662 – 641), 1561 – 1582 cal yr BP (AD 389 – 368), 1645 – 1666 cal yr BP (AD 305 – 284) and 1834 – 1855 cal yr BP (AD 116 – 95) (Fig. 3.6). The mean fire return interval (FRI) was 182 years (Fig. 3.7). These results are consistent with fire-history reconstructions from low-elevation (<2400 m) *Pinus contorta* forests in Yellowstone National Park, which indicate an average fire return interval of 135-185 years (Schoennagel et al., 2003). This period was marked by positive PDSI values (Fig. 2.6), suggesting cooler, moister conditions than present. The relatively long FRI values, compared with Yellowstone data, are consistent with the effectively wetter conditions at this time, inferred from positive PDSI values between 1700-1200 cal yr BP (AD 250-750).

#### 1200 – 600 cal yr BP (AD 750 – 1350)

Of the 14 fire episodes identified during this time period at all three sites, two occurred at more than one site. A widespread fire episode was observed at Cape Horn II and Decker lakes as a fire episode at ca. 1040 – 1060 cal yr BP (AD 890 - 910). Hidden and Decker lakes also shared a fire episode at ca. 660-670 cal yr BP (AD 1280 - 1290). No fire episodes were registered at all three sites, although on longer centennial time scales, multiple fires occurred at 850 – 950 cal yr BP (AD 1000 - 1100), 1000 – 1100 cal yr BP (AD 850 - 950) and 1100 – 1200 cal yr BP (AD 750 - 850) (Fig. 3.6).

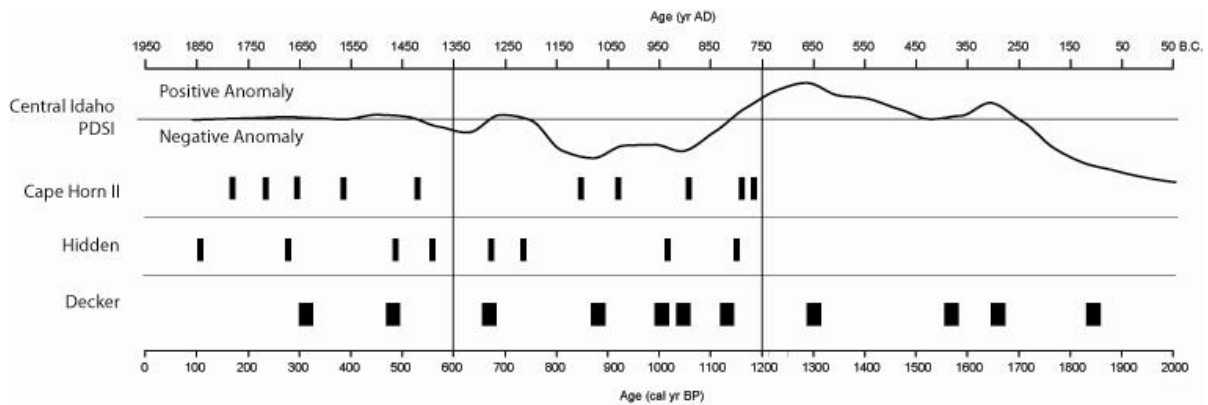


Figure 3.6. Simplified patterns of burning at all study sites. Black squares represent fire episodes and their widths are proportional to the sample resolution from each site. The upper line represents annually reconstructed values of the Palmer Drought Severity Index (PDSI) smoothed using locally weighted regression (LOWESS) with a smoothing parameter of 200 years. Positive PDSI values indicate wetter cooler periods, whereas negative values indicate warmer drier periods.

At Decker Lake during the time period 600-1200 cal yr BP (AD 750 – 1350), the average time between fire events was 124 years, and fires were more frequent than during previous time period (Fig. 3.7) although a t-test proved this difference to not be significant ( $\alpha = .05$ ). BCHAR was also low during this period, suggesting smaller fires with less charcoal production. At Cape Horn II, average FRI was 84 years, whereas nearby Hidden Lake registered a FRI of 142 years. Both sites register FRI values that are lower than observed at Decker Lake during the previous time period, although the differences not statistically significant.

At Decker Lake, the average time between fire events decreased from 182 years at 1200-2000 cal yr BP (AD 750 – BC 50) to 124 years at 600-1200 cal yr BP (Fig. 3.7). Average FRI values were lower than present at Cape Horn II and Hidden Lake, although not significantly. The FRI values observed at Cape Horn II and Decker Lake (although not

significant) were shorter than average FRI values for *Pinus contorta* forests in Yellowstone National Park at present (135 – 180 years between fire events; Schoennagel et al. 2003) suggesting that burning was elevated during this time period. Although average FRI values decreased at Decker Lake, the change was not statistically significant ( $\alpha = .05$ ) from the previous period. During this time period (600 – 1200 cal yr BP), FRI among sites was also not significantly different.

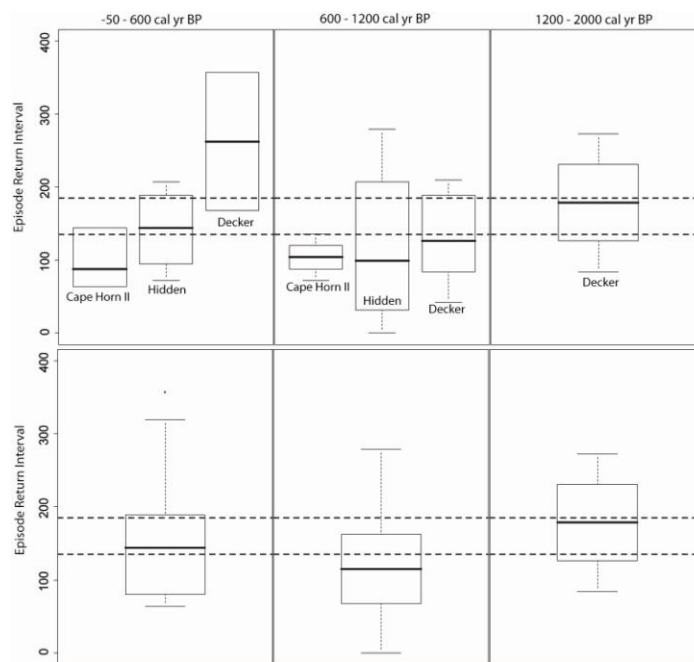


Figure 3.7. Boxplots of fire-return intervals from each site (top row) and collectively between sites (bottom row) for each time period. Dashed lines represent average fire return intervals for similar lodgepole pine forests in Yellowstone National Park (Schoennagel et al., 2003)

Reconstructed PDSI data from central Idaho show that the warmest, driest period of the last 2000 years occurred between 1120 and 780 cal yr BP (AD 830 – 1170) (Fig. 3.5; Cook et al., 2004) during the broadly defined MCA ((MCA; 1050 – 650 cal yr BP; Pierce et al.,

2004)). It is likely that greater drought in summer and drier fuels explain the observed increase in fires in the three study sites, although the differences from present are not statistically significant. Independent evidence of regional drought at 1200 – 600 cal yr BP (AD 750 – 1350) comes from other records in the northern Rockies. For example, in upper-elevation forests of Yellowstone National Park, Meyer and Pierce (2003) observed an increase in fire-related debris flows at this time. A charcoal record from Burnt Knob Lake, a high-elevation site in east-central Idaho, registered an increase in charcoal accumulation rates associated with MCA warming (Brunelle and Whitlock, 2003). Reservoir Lake in southwestern Montana also shows an increase in fire activity during this time period (see Chapter 4 of this thesis).

#### 600 cal yr BP – present (AD 1350 – 2005)

Eleven fire episodes were recorded among the sites, and one occurred at both Cape Horn II and Hidden lakes at roughly 287 cal yr BP (AD 1663). On longer time scales, periods of burning occurred at all sites between 280 and 320 cal yr BP (AD 1670 and 1630). Average FRI values at Cape Horn and Hidden lakes indicate no statistical change in fire activity in the last 600 years from the previous period. Decker Lake appears to have a higher FRI during this time period, although again the results are not significant.

PDSI data from central Idaho do not show wetter conditions during the LIA (750 – 50 cal yr BP; Meyer and Pierce, 2003) and values rarely exceed 0 (Cook et al., 2004). The lack of a strong climate signal in the Sawtooth region may explain the insignificant change in fire activity from the previous period. Average FRI at Cape Horn II Lake

increased to 134 years between episodes during the period of 600 - -50 cal yr BP (AD 1350 – 1900), although it was not a statistically significant change from the previous period.

Other proxy studies in the western United States show a stronger response to climate changes during the LIA than was evident in this study. Meyer and Pierce (2003) observed fewer fire-related debris flows in upper-elevation forests at Yellowstone National Park at 750-50 cal yr BP (AD 1200 – 1900). They attributed this decrease to wetter fuels and fewer fires during a period of cooler, wetter conditions than at present. Carrara and McGimsey (1981) and Luckman et al. (1993) found that glaciers in the Northern Rockies reached their maximum extent during the LIA. Brunelle and Whitlock (2003) found that fire frequency decreased at Burnt Knob Lake in Idaho during the period of 550-150 cal yr BP (AD 1400 – 1800). Thus, LIA cooling was registered in some proxy records from the region.

The mining period of the late 19<sup>th</sup> century (70 cal yr BP; AD 1880) was not associated with increased fire occurrence at the three study sites, although a fire episode at AD 1853 – 1844 at Hidden Lake could have been caused by mining activities. Ranching during the 20<sup>th</sup> century also does not appear to have altered the fire frequency at the study sites, as no peaks are detected during this time period.

In the 1930s, fire suppression became effective to the point that the annual extent of fires in the Northern Rocky Mountains was reduced (Arno et al., 2000). The large fires in recent years (Fig. 3.5) include the Rabbit Creek, Valley Road and Trail Creek

fires, which occurred in remote mountainous areas. It is likely that these fires were allowed to burn, in accordance with a shift in Sawtooth Wilderness fire management policy in the early 1980s from one focused on active fire suppression to one that aims to restore natural fire patterns in wilderness areas (Fischer, 1984).

### Conclusions

Charcoal data from Cape Horn II, Hidden and Decker Lakes provide a record of how fire frequency has varied in the Sawtooth Mountains during the last 2000 years. Comparing these data with other records of climate change, such as PDSI reconstructions (Cook et al., 2004) and other paleo studies (Brunelle and Whitlock, 2003; Meyer and Pierce, 2003), helps clarify how fire activity may have responded to landscape-scale climate variation. These comparisons also provide an opportunity to test whether widely observed climate events, such as the MCA and LIA occurred in central Idaho (as inferred through PDSI reconstructions) and if fire dynamics responded to these changes.

There seems to be no statistically significant change in temporal trends in FRI at the three sites, and little difference among sites for the same period. These results suggest that climate variations at magnitudes of the MCA and LIA did not affect the fire history of these forests. This was not the case in the forests in Yellowstone National Park and other regions of Idaho, where fire activity did respond to MCA and LIA climate variations (Meyer and Pierce, 2003; Brunelle and Whitlock, 2003).

PDSI data indicate effectively drier conditions in the Sawtooth Mountains during the MCA, but little climate change from present during the LIA. Decker Lake was the only site that provided fire-history information prior to the onset of the MCA and it shows a decrease in average FRI around the time of the MCA from previous values (although not statistically significant). Two of the sites, show the same FRI in the MCA as observed in present-day *Pinus contorta* forests in Yellowstone National Park, suggesting increased fire activity at that time (Schoennagel et al. 2003). PDSI data from the later part of the record (AD 1350 – 1950) do not indicate cooler, moister conditions associated with the LIA. However, fire activity in the last 100 years do show less burning (although not significantly so) that would suggest cooler moister conditions during this period or possibly a response to forest management policies.

Of the 25 fire episodes recorded among the study sites, only three occurred at the same time (AD 890 – 910, AD 1280 – 1290, AD 663).

The influence of humans in shaping the fire regime appears to have been minimal throughout the last 2000 years, inasmuch as fires more closely tracked variations in the PDSI than important events in human history. If Native Americans were burning prior to Euro-American arrival, their influence on fire occurrence was ultimately controlled by climate (e.g. PDSI).

The arrival of Euro-Americans and subsequent mining development also did not appear to have influenced fire frequency. One fire episode in 1850s at Hidden Lake could possibly have been set by humans, but there was no period of elevated burning to

suggest a strong influence of early miners. The 20<sup>th</sup> century shows no charcoal peaks in any of the records. This would suggest that none of the sites have burned during this period; however, fires have occurred in the 19<sup>th</sup> and 20<sup>th</sup> centuries in the Sawtooth National Forest (Fig. 3.5). Having more sites and higher sampling resolution would produce a more spatially and statistically robust dataset and better illustrate spatial variations in regional burning.

### References Cited

- Arno, S. F., D. J. Parsons, and R. E. Keane. 2000. Mixed-severity fire regimes in the Northern Rocky Mountains: consequences of fire exclusion and options for the future. Pp. 225-232 in D. N. Cole, S. F. McCool, W. T. Borrie, J. O'Loughlin, compilers, Wilderness science in a time of change conference - Volume 5: wilderness ecosystems, threats and management. USDA Forest Service Rocky Mountain Research Station, Proceedings RMRS-P-15-VOL-5.
- Barrett, S. W., and Arno, S. F. (1982). Indian Fires as an Ecological Influence in the Northern Rockies. *Journal of Forestry* 80, 647-651.
- Biondi, F., Perkins, D.L., Cayan, D.R., Hughes, M.K. (1999). July Temperature During the Second Millennium Reconstructed from Idaho Tree Rings. *Geophysical Research Letters* 26, 1445-1448
- Boerner, R. E. J. (1982). Fire and Nutrient Cycling in Temperate Ecosystems. *BioScience* 32, 187-192.
- Brunelle, A., and Whitlock, C. (2003). Postglacial fire, vegetation, and climate history in the Clearwater Range, Northern Idaho, USA. *Quaternary Research* 60, 307-318.
- Brunelle, A., Whitlock, C., Bartlein, P., and Kipfmüller, K. (2005). Holocene fire and vegetation along environmental gradients in the Northern Rocky Mountains. *Quaternary Science Reviews* 24, 2281-2300.
- Butler, B. Robert. (1963). An Early Man Site at Camas Prairie, Southcentral Idaho. *Tebiwa* 6(1):22-33. Pocatello
- Carrara, P. E., and McGimsey, R. G. (1981). The Late-Neoglacial Histories of the Agassiz and Jackson Glaciers, Glacier National Park, Montana. *Arctic and Alpine Research* 13, 183-196.
- Clark, J. S., and Royall, P. D. (1996). Local and Regional Sediment Charcoal Evidence for Fire Regimes in Presettlement North-Eastern North America. *The Journal of Ecology* 84, 365-382.
- Clark, J. S., Royall, P. D., and Chumbley, C. (1996). The Role of Fire During Climate Change in an Eastern Deciduous Forest at Devil's Bathtub, New York. *Ecology* 77, 2148-2166.

CMIP climate data. World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset. available online: [http://gdo-dcp.ucllnl.org/downscaled\\_cmip3\\_projections/#Welcome](http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/#Welcome)

Cook, E. R., Woodhouse, C. A., Eakin, C. M., Meko, D. M., and Stahle, D. W. (2004). Long-Term Aridity Changes in the Western United States. *Science* 306, 1015-1018.

Dean, W. E. (1974). Determination of Carbonate and Organic-Matter in Calcareous Sediments and Sedimentary-Rocks by Loss on Ignition - Comparison with Other Methods. *Journal of Sedimentary Petrology* 44, 242-248.

Fisher, F. S., McIntyre, D. H., and Johnson, K. M. (1992). Geologic map of the Challis 1× 2 quadrangle. Idaho: US Geological Survey Miscellaneous Investigation Series Map I-1819, scale 1.

Gallagher, Joseph G. (1975). The Archaeology of the Sheepeater Battleground and Redfish Overhang: Settlement Model for Central Idaho. Master's Thesis, Idaho State University.

Gavin, D. G., Hu, F. S., Lertzman, K., and Corbett, P. (2006). Weak climatic control of stand-scale fire history during the late Holocene. *Ecology* 87, 1722-1732.

Hallett, D. J., and Hills, L. (2006). Holocene vegetation dynamics, fire history, lake level and climate change in the Kootenay Valley, southeastern British Columbia, Canada. *Journal of Paleolimnology* 35, 351-371.

Higuera, P. E., Brubaker, L. B., Anderson, P. M., Brown, T. A., Kennedy, A. T., and Hu, F. S. (2008). Frequent Fires in Ancient Shrub Tundra: Implications of Paleorecords for Arctic Environmental Change. *PLoS ONE* 3.

Idaho Historical Society. (1982). Available online: <http://www.idahohistory.net/Reference%20Series/0282.pdf>

Ipcc, C. C. (2007). The Physical Science Basis-Summary for Policymakers. R. Alley et al., 18pp,(2007)(<http://ipcc-wg1.ucar.edu/>).

Long, C. J., Whitlock, C., Bartlein, P.J., and Millspaugh, S.H. (1998). A 9000-Year Fire History From the Oregon Coast Range, Based on High-Resolution Charcoal Study. *Canadian Journal of Forest Research* 28, 774-787.

Luckman, B. H., Holdsworth, G., and Osborn, G. D. (1993). Neoglacial glacier fluctuations in the Canadian Rockies. *Quaternary Research* 39, 144-153.

Lyford, M. E., Jackson, S. T., Betancourt, J. L., and Gray, S. T. (2003). Influence of landscape structure and climate variability on a late Holocene plant migration. *Ecological Monographs* 73, 567-583.

Meyer, G. A., and Pierce, J. L. (2003). Climatic controls on fire-induced sediment pulses in Yellowstone National Park and central Idaho: a long-term perspective. *Forest Ecology and Management* 178, 89-104.

Miller, M., (1965). The history of Sawtooth and Virginia City. *Idaho Yesterdays* 9, 11-16.

Millspaugh, S. H., Whitlock, C., and Bartlein, P. J. (2000). Variations in fire frequency and climate over the past 17 000 yr in central Yellowstone National Park. *Geology* 28, 211-214.

National Inter-Agency Fire Center. available online: <http://www.nifc.gov/>

Pederson, G. T., Fagre, D. B., Gray, S. T., and Graumlich, L. J. (2004). Decadal-scale climate drivers for glacial dynamics in Glacier National Park, Montana, USA. *GEOPHYSICAL RESEARCH LETTERS* 31, L12203.

Pierce, J. L., Meyer, G. A., and Jull, A. J. (2004). Fire-induced erosion and millennial-scale climate change in northern ponderosa pine forests. *Nature* 432, 87-90.

Power, M. J., Whitlock, C., Bartlein, P., and Stevens, L. R. (2006). Fire and vegetation history during the last 3800 years in northwestern Montana. *Geomorphology* 75, 420-436.

R Core Development Team. (2008) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.

Schoennagel, T., Turner, M. G., and Romme, W. H. (2003). Influence of fire interval and serotiny on post-fire lodgepole pine (*Pinus contorta* var *latifolia* Engelm) density in Yellowstone National Park (USA). *Ecology* 84, 2967-2978.

Stuiver, M., and Reimer, P. J. (1993). Extended C-14 Data-Base and Revised Calib 3.0 C-14 Age Calibration Program. *Radiocarbon* 35, 215-230.

Veblen, T. T., Kitzberger, T., and Donnegan, J. (2000). Climatic and Human Influences on Fire Regimes in Ponderosa Pine Forests in the Colorado Front Range. *Ecological Applications* 10, 1178-1195.

Westerling, A. L., Hidalgo, H. G., Cayan, D. R., and Swetnam, T. W. (2006). Warming and earlier spring increase western US forest wildfire activity. *Science* 313, 940-943.

Whitlock, C. (1993). Postglacial Vegetation and Climate of Grand-Teton and Southern-Yellowstone-National-Parks. *Ecological Monographs* 63, 173-198.

Whitlock, C., and Larsen, C. (2001). Charcoal as a fire proxy. *Tracking environmental change using lake sediments* 3, 75-97.

Whitlock, C., and Millspaugh, S. H. (1996). Testing the assumptions of fire-history studies: an examination of modern charcoal accumulation in Yellowstone National Park, USA. *The Holocene* 6, 7.

## CHAPTER 4

AN ANALYSIS OF HIGH-RESOLUTION RECORDS OF HOLOCENE FIRE FROM THE  
NORTHERN ROCKY MOUNTAINS, USAIntroduction

Holocene climate variations in the northern Rocky Mountains has caused changes in both wildfire dynamics (Millspaugh et al., 2000; Brunelle et al., 2005) and vegetation composition (e.g., Whitlock, 1993; Lyford et al., 2003). Fire is and has been an important natural form of disturbance in the Northern Rocky Mountains, influencing forest composition and aiding in nutrient cycling (Boerner, 1982). Climate change occurs on multiple time scales. On millennial time scales, variations in the seasonal cycle of insolation have been a primary driver of changes in the strength and position of atmospheric circulation and regional climate (Bartlein et al., 1998). On centennial and shorter time scales, climate change is driven by processes such as the El Niño Southern Oscillation and by distinct events such as volcanic eruptions. On shorter time scales tree rings can provide annually resolved data illustrating changes in patterns of drought variability (Cooke et al., 2004).

In the Northern Rocky Mountains, proxy records of changes in Holocene climate are often widely spaced and derived from a variety of sources. Fossil pollen (Whitlock, 1993; Brunelle et al., 2005), plant macrofossils (Lyford et al., 2003), sediment charcoal (Power et al., 2006) and tree rings (Biondi and Perkins, 1999; Pederson et al., 2004), for example, show changes in vegetation and fire that indicate a response to climate

variations at temporal scales ranging from millennial to annual time scales. On longer time scales, a warmer drier period associated with increased summer insolation in the early Holocene (c.a. 10,000 cal yr BP) is registered in lake-sediment records as a period when xerothermic taxa increased, upper treeline expanded, and fire activity was elevated (Millsbaugh et al., 2000). On centennial-scale events, such as the Medieval Warm Period (1150 – 650 cal yr BP; Cronin et al., 2003), are registered in Northern Rocky Mountain lake-sediment records as changes in sedimentation, vegetation, and fire regime (Campbell, 1998; Whitlock et al., 2003). On decadal and annual time scales, lake sediments provide records of vegetation and landscape change in northwestern Montana (Power et al., 2006). This study focuses on climate changes and their impacts on fire regimes at centennial time scales.

In the northern Rocky Mountains, paleofire records reconstructed from charcoal data in lake sediments show distinct changes in fire activity during the Holocene in response to both climate and vegetation change occurring on millennial time scales. For example, Brunelle et al. (2005) investigated changes in vegetation and fire frequency in lake sites along a precipitation gradient in northwestern Montana and northern Idaho. Based on the ratio of July vs. annual precipitation at present, sites were categorized as either “summer wet” or “summer dry” (Brunelle et al., 2005). At present, summer-dry sites are more strongly influenced by the northeastern Pacific subtropical high, which suppresses summer precipitation at present. Summer-wet sites, in contrast, receive some level of rainfall from summer monsoonal circulation. During the early-Holocene

period, paleoclimate model simulations suggest that increased summer insolation strengthened both the subtropical high and summer monsoonal circulation (Bartlein et al. 1998). Whitlock and Bartlein (1993) and Brunelle et al. (2005) speculated that summer-wet areas became wetter than at present, and summer-dry regions became drier in the early Holocene as a result. Both pollen-based vegetation and charcoal-based fire records have been used to test this hypothesis. For example, Brunelle et al. (2005) found evidence of increased fire activity in the early Holocene at summer-dry sites in the Northern Rocky Mountains, and evidence of decreased fires at a summer wet site.

Mehring et al. (1977) examined a postglacial record of vegetation and fire from Lost Trail Pass Bog (45.692, 113.953, 2155 m elevation, .69 ha), located in subalpine forest in the Bitterroot Range of southwestern Montana. Charcoal levels in last 2000 years were higher than in the previous 9500 years. This high fire activity was ascribed to late-Holocene increases in anthropogenic burning but the signal is also typical of a summer-wet response. The increase of xerothermic taxa and upslope shift in low-elevation conifers in the early Holocene was consistent with longer growing seasons during the early-Holocene insolation maximum than at present.

At low elevations 43 km east from Lost Trail Pass Bog (LTPB), Pintlar Lake (45.841° N, 113.439° W, 1924 m elevation, 4.7 ha lake size) offers paleoecological information from the lower forest border. A study of the pollen and charcoal was described as a summer-wet response with low fire activity in the early Holocene,

followed by increasing fires in the middle and late Holocene. Brunelle et al. (2005) attributed the evidence of low fire activity in the early Holocene followed by an increase in fires in the late Holocene to a weakening of the summer monsoon in response to decreasing insolation in the last 9000 years.

My objective was to examine the fire history of another low-elevation site in southwestern Montana to confirm the reconstruction offered by Pintlar Lake. This chapter describes a high-resolution charcoal record from Reservoir Lake, MT (45.124° N, 113.456° W, 2155 m elevation, 14.5 ha), which was undertaken as part of a larger project to reconstruct the ecological history of the Beaverhead Range, based on multiple proxies. The project is headed by Dr. Eric Grimm at the Illinois State Museum. Reservoir Lake is located at the southern end of the Big Hole valley, 79 km south of Pintlar Lake but in a similar ecological setting (Fig. 4.1). To facilitate comparison with Reservoir Lake data, charcoal data from Pintlar Lake (Fig. 3.1; Brunelle et al., 2005) were re-analyzed using a new age model and a new decomposition approach (ref). The objectives of this study were to address the following questions: 1) how has fire frequency varied during the last 14,000 years at Reservoir Lake and what are the likely controls of past fire activity, and 2) how does the fire record from Reservoir Lake compare with other information on past climate and fire from the Northern Rocky Mountains, particularly in Big Hole region as inferred from Pintlar Lake?

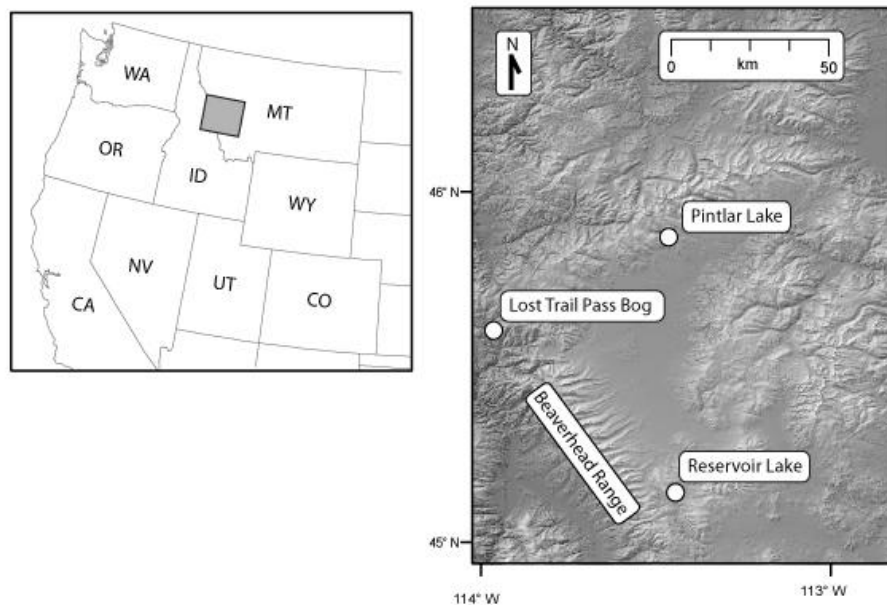


Figure 4.1. Map of the study region showing Reservoir Lake, Pintlar Lake (Brunelle et al., 2005) and Lost Trail Pass Bog (Mehring et al., 1977)

Reservoir Lake is dammed by a terminal end moraine created by late-Pleistocene glaciers emanating from the Beaverhead Range (Locke, 1990). An extrapolated age for the base of the sediments is 14,000 cal yr BP, suggesting that ice recession and the formation of the lake occurred sometime before then.

The Big Hole region receives most of its precipitation during the winter and the spring. Temperatures vary widely throughout the year with summer highs in the upper 20°C and winter lows plunging well below -20°C. Present-day circulation patterns show a distinct seasonal pattern. During summer months, precipitation comes from convective thunderstorms with moisture derived from the Gulf of Mexico and Gulf of California (Mock, 1996). In the winter and spring, storm tracks are generally from the west, originating in the Pacific Ocean. Spatially interpolated precipitation data from the

Reservoir Lake region for the time period of 1995-2005 (PRISM group, 2008) suggest that all seasons receive moisture, but the majority of precipitation is received in winter and spring. Spring precipitation (March, April and May) averages 185 cm, summer precipitation (June, July and August) is 107 cm, fall precipitation (September, October and November) is 125 cm, and winter (December, January and February) receives 154 cm, mostly as snow. Present vegetation at Reservoir Lake is dominated by *Pseudotsuga menziesii* (Douglas-fir) and *Pinus contorta* (lodgepole pine). Steppe vegetation, dominated by sagebrush (*Artemisia tridentata*) and grasses (*Poaceae*), lies just 3 km to the southeast. The mixed conifer forest surrounding Reservoir Lake supports a modern fire regime with return intervals of 30 – 70 years between fire events (Brown and Smith, 2000), but the site has not burned in recent decades (B. Bracht, pers. comm., 2008).

### Methods

During winter 1996, a 15.65-m-long sediment core was recovered from Reservoir Lake using a modified Livingstone corer (Wright et al., 1984). Cores were extruded and wrapped in plastic wrap and aluminum foil before being transported to Illinois State Museum Research and Collections Center in Springfield, IL for refrigeration.

For charcoal analysis, 2 cm<sup>3</sup> of sediment were taken at contiguous 1-cm intervals through the core. A total of 1600 samples were processed for charcoal analysis.

Samples were soaked in a solution of 5% sodium hexametaphosphate and 6% bleach for 24 hours, and then washed through nested 125µm and 250µm sieves. The residue was

rinsed into Petri dishes and charcoal particles were tallied under a stereoscope at magnifications of 40-80X. Charcoal counts were divided by sample volume to calculate charcoal concentration (particles  $\text{cm}^{-3}$ ), and charcoal accumulation rates (particles  $\text{cm}^{-2} \text{yr}^{-1}$ ) were calculated by multiplying concentration by sediment accumulation rate ( $\text{cm yr}^{-1}$ ) (Whitlock and Larsen, 2001).

At both Reservoir and Pintlar lakes, accelerator mass spectrometer (AMS)  $^{14}\text{C}$  dating,  $^{210}\text{Pb}$  dating, and tephrochronology were used to build a chronology for the sediment sequences (Table 4.2). Radiocarbon dates were calibrated using CALIB 5.1.0 software to cal yr BP, with AD 1950 as 0 cal yr BP (Stuvier et al., 1998). Tephra from the eruption of Mt. Mazama in southwestern Oregon was found at a depth of ~728 cm and assigned an age of  $6730 \pm 40$  14C yr BP (7596 cal yr BP) based on Hallett et al. (1997).

Age-depth models (Fig. 4.2) were constructed using a spline based modeling procedure (Higuera et al., 2008) that calculated 95% upper and lower confidence intervals throughout the course of 1,000 Monte Carlo iterations. In each iteration, a spline was fit to the probability density function obtained from the calibration using CALIB 5.1.0 and IntCAL software (Stuvier et al., 1998).

Table 4.1. Age information used to construct chronologies for Reservoir and Pintlar lakes.

| Site                      | Top Depth (cm) | Bottom Depth (cm) | Age (14 C yr BP) | 14C Error (years) | Cal yr BP | Lab Number   | Information                                     |
|---------------------------|----------------|-------------------|------------------|-------------------|-----------|--------------|-------------------------------------------------|
| Reservoir Lake            | 0              | 1                 | na               | na                | -50       | na           | Sediment Surface                                |
|                           | 27             | 28                | na               | na                | -30       | na           | <sup>210</sup> Pb Date                          |
|                           | 51             | 52                | na               | na                | 40        | na           | <sup>210</sup> Pb Date                          |
|                           | 226.0          | 227.0             | 1340             | 35                | 1275      | CAMS-118868  |                                                 |
|                           | 299.0          | 300.0             | 2095             | 35                | 2066      | CAMS-118867  |                                                 |
|                           | 357            | 358               | 2545             | 30                | 2631      | CAMS-116257  |                                                 |
|                           | 709.5          | 710.5             | 6150             | 35                | 7061      | CAMS-116258  |                                                 |
|                           | 724.5          | 725.5             | 6570             | 35                | 7470      | CAMS-116262  |                                                 |
|                           | 728            | 772               | 6730             | 40                | 7596      | na           | Mt. Mazama Tephra (Hallet et al., 1997)         |
|                           | 773            | 774               | 6885             | 40                | 7717      | CAMS-116263  |                                                 |
|                           | 910            | 911               | 9405             | 35                | 10634     | CAMS-116259  |                                                 |
|                           | 1076           | 1097              | 10070            | 40                | 11625     | UCIAMS-38382 |                                                 |
|                           | 1309           | 1310              | 11795            | 40                | 13668     | CAMS-116260  |                                                 |
|                           | 1563           | 1564              | 12290            | 35                | 14153     | CAMS-116261  |                                                 |
| Pintlar Lake <sub>1</sub> | 0              | 1                 | na               | na                | -45       | na           | Sediment Surface                                |
|                           | 165            | 166               | 1795             | 50                | 1724      | WIS-2175     |                                                 |
|                           | 325            | 326               | 2130             | 160               | 2119      | WIS-2177     |                                                 |
|                           | 451            | 452               | 4120             | 60                | 4655      | WIS-2178     |                                                 |
|                           | 608            | 609               | 5830             | 70                | 6636      | WIS-2179     |                                                 |
|                           | 747            | 748               | 8220             | 80                | 9195      | WIS-2180     |                                                 |
|                           | 807            | 808               | 9860             | 90                | 11300     | WIS-2181     |                                                 |
|                           | 827            | 828               | 10690            | 100               | 12723     | WIS-2182     |                                                 |
|                           | 932            | 940               | 11200            | na                | 13109     | na           | Glacier Peak Tephra (Carrara and Trimble, 1992) |

<sup>1</sup>Data comes from Brunelle et al., 2005<sup>2</sup> CALIB 5.1.0<sup>2</sup>Calibration program was used.

The charcoal records at both Reservoir and Pintlar lakes were decomposed into two components, a slowly varying background component (BCHAR) and a high frequency peaks component (Clark et al., 1996; Long et al., 1998). BCHAR is usually attributed to charcoal from regional fires or from secondary material washed into the lake (Clark and Royal, 1996; Whitlock and Millspaugh, 1996; Marlon et al., 2006; Higuera et al., 2007). The positive deviations above a prescribed BCHAR threshold comprise the charcoal peaks component, which is interpreted as representing local fire episodes occurring within the local area of the site (i.e., 500 – 1000 m radius of lake; Lynch et al., 1994). To distinguish between BCHAR and charcoal peaks, we used CharAnalysis software (Higuera et al., 2008; [www.montana.edu/phiguera/](http://www.montana.edu/phiguera/)), which is a freeware program for analyzing charcoal time series data.

BCHAR was modeled using a LOWESS smoother robust to outliers. Brunelle et al. (2005) used a 600-year window width at Pintlar Lake, and that value was also used for the Reservoir Lake data to facilitate comparison. Charcoal peaks were identified using a Gaussian mixture model, similar to that of Gavin et al. (2006). The 95 percentile of the distribution was selected as a threshold in separating significant charcoal peaks from the noise component. Because overall charcoal production in the area likely varied over time with changing fuel composition, climate, and fire regime, the Gaussian mixture model was applied locally and only considered samples in the 500 years before and after each level. The significance of charcoal peaks was further determined with a minimum count test that compares the peak with the minimum charcoal value within 75 years

window prior to the peak. If the probability that this minimum value came from the same two-sided Poisson distribution as the identified peak ( $\alpha < 0.05$ ), then the peak was deemed significant. Fire frequency was calculated by summing the total number of peaks within a 1000-year moving window centered on each sample. Fire episodes were summarized with a 2000-year moving window, in keeping with the original Pintlar Lake analysis (Brunelle et al., 2005) to display millennial scale variations in fire-episode frequency. Figures were plotted using the statistical environment R (R core development team, 2008).

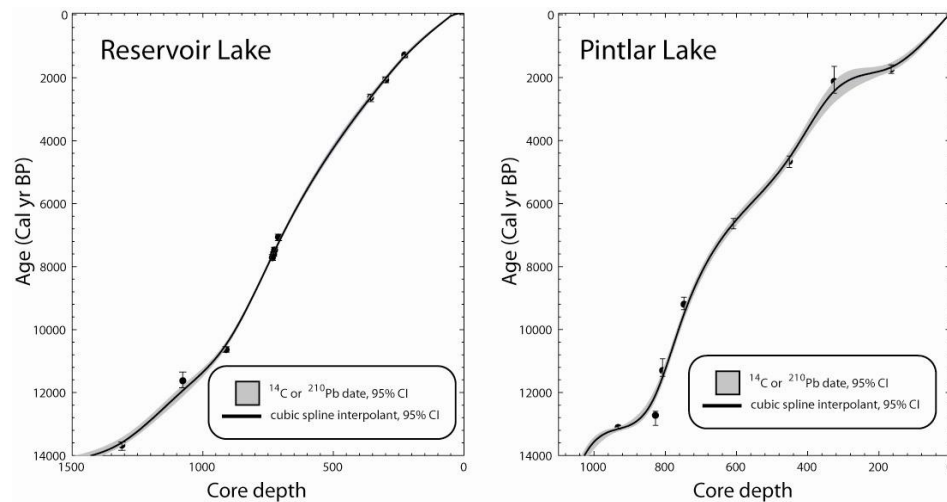


Figure 4.2. Age-depth relationships from Reservoir and Pintlar lakes. Black line indicates interpolated age-depth values. Gray shading indicates 95% confidence interval of each age depth model. Individual age determinations are indicated by black circles with standard error bars. Software used for this analysis was CharAnalysis (Higuera et al., 2008; [www.montana.edu/phiguera/](http://www.montana.edu/phiguera/)).

## Results

Sediments from Reservoir Lake were composed of three distinct units. The upper 1 meter of sediment (-50 – 700 cal yr BP) was homogenous fine-detritus gyttja with no visible laminations (Fig. 3.3). The majority of the core (100 – 1350 cm depth, 700 – 11,800 cal yr BP) was homogenous fine-detritus gyttja with fine laminations. Below 1180 cm depth (> 11,800 cal yr BP), the sediment was a clay gyttja with fine laminations. The low organic content in the bottom of the core probably reflects less organic productivity in the watershed during the late-glacial period.

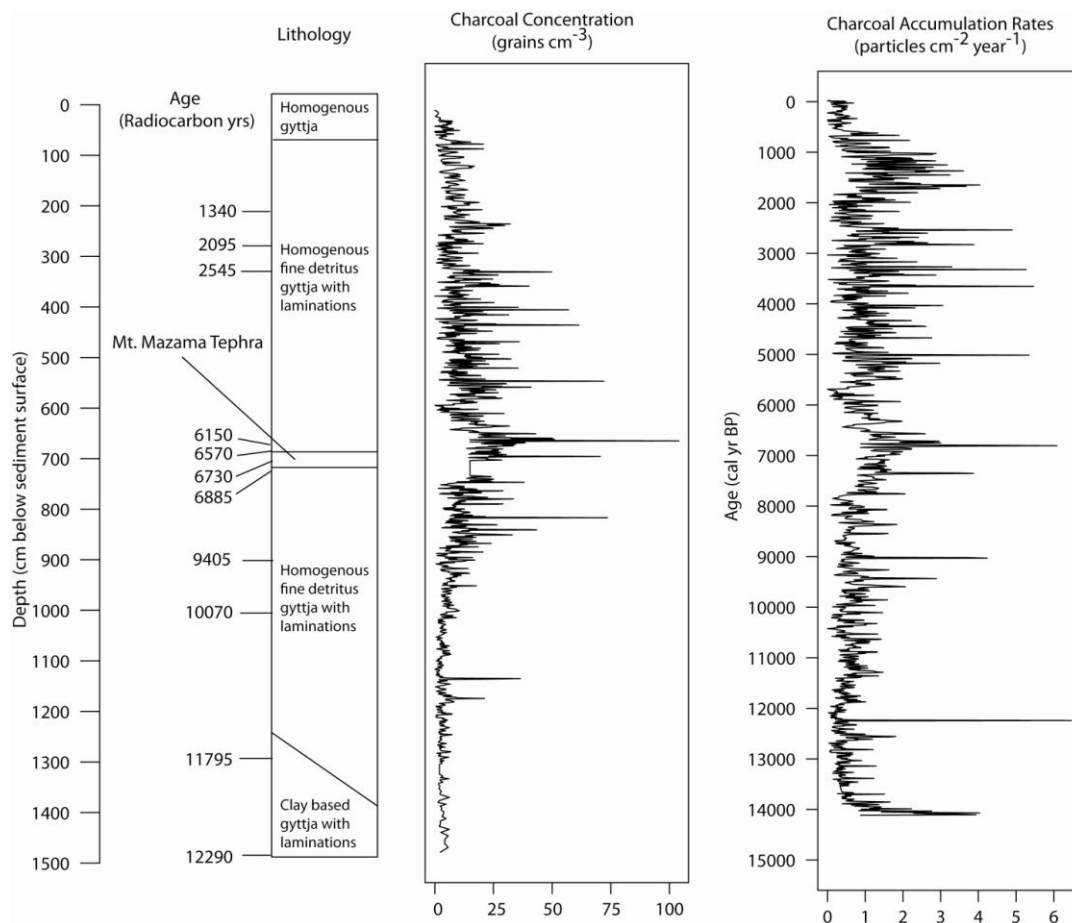


Figure 4.3. Lithology, <sup>14</sup>C dates, charcoal concentration and charcoal accumulation rates from Reservoir Lake.

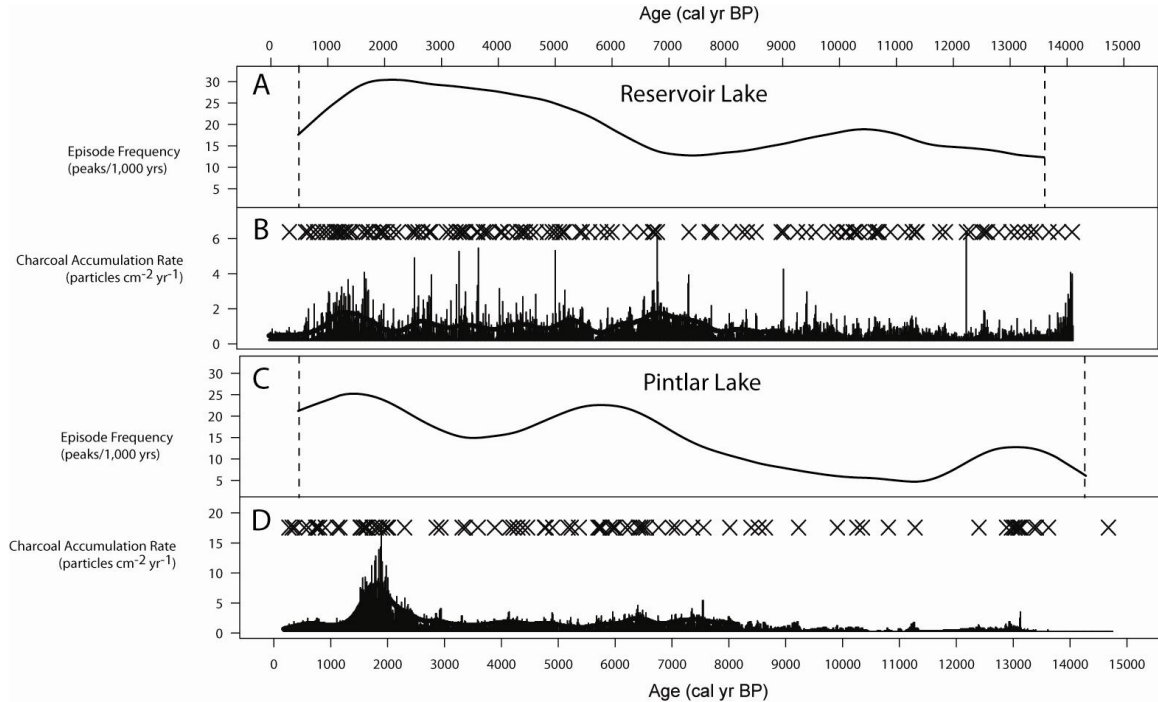


Figure 4.4. Fire-history information for Reservoir Lake (A and B) and Pintlar Lake (C and D). Interpolated episode frequency (A and C). BCHAR (smoothed lines; B and D), charcoal accumulation rates (vertical bars; B and D) and identified, significant charcoal peaks (X marks; B and D).

At Reservoir Lake, BCHAR levels were low from 13,500 to 8000 cal yr BP (.5 particles  $\text{cm}^{-2} \text{yr}^{-1}$ ) (figure 4.4 B). Values increased gradually to 2 particles  $\text{cm}^{-2} \text{yr}^{-1}$  reaching highest levels at 7000 cal yr BP. After 7000 cal yr BP, BCHAR levels decreased until 5700 cal yr BP before remaining stable until late Holocene. A second period of high BCHAR occurred at 1500 cal yr BP (Fig. 4.4 B).

At Pintlar Lake, BCHAR had high levels at 13,000 cal yr BP (.2 particles  $\text{cm}^{-2} \text{yr}^{-1}$ ), then decreased at 12,800 cal yr BP followed by a slow increase until 7000 cal yr BP (.5 particles  $\text{cm}^{-2} \text{yr}^{-1}$ ) (Fig. 4.4 D). BCHAR remained steady at values of 2 particles per  $\text{cm}^{-2} \text{yr}^{-1}$  before rapidly increasing at 2000 cal yr BP. BCHAR was greatest at 1800 cal yr BP and decreased to lower values near present day (figure 4.4 D).

Fire frequency at Reservoir Lake was 15 episodes/1000 years during the late-glacial period > 13,000 cal yr BP (Fig. 4.4 A). Fire frequency slowly increased and peaked at 10,500 cal yr BP with values of 17 episodes/1000 years. After 10,500 cal yr BP, it decreased until 7200 cal yr BP when values reached 13 episodes/1000 years. After 7200 cal yr BP, fire frequency increased steadily and peaked at 2000 cal yr BP with the highest values observed during the record (27 episodes/1000 years). Fire frequency has since decreased in the recent part of the record (Fig. 4.4 A). Fire frequencies were not interpreted for first and last 500 years of either record (Fig. 4.4 A and D, dashed lines) because calculating the number of episodes with a 2000-yr smoothing window produced erroneous results.

At Pintlar Lake, fire frequency was low during the late-glacial period (7 episodes/1000 years), formed a broad peak at 13,200 and 12,800 cal yr BP (10 episodes/1000 years) before decreasing to a low point at 11,400 cal yr BP (7 episodes/1000 years). After 11,400 cal yr BP, fire frequency steadily increased to 20 episodes/1000 years at 6000 cal yr BP before decreasing to a low point of 15 episodes/1000 years at 3200 cal yr BP. After 3200 cal yr BP, fire frequency increased to the highest values of the record (1100 cal yr BP; 23 episodes/1000 years). Since 1100 cal yr BP, fire frequency has slowly decreased.

## Discussion

Pollen- and charcoal-based records of vegetation and fire history in the northern Rocky Mountains (e.g., Mehringer et al., 1977; Brunelle et al., 2005; Millspaugh et al., 2000; Brunelle and Whitlock, 2003) provide a framework for interpreting the data from Reservoir and Pintlar lakes. A detailed pollen record from Pintlar Lake (Brunelle et al., 2005) was used to infer the vegetation history at Reservoir Lake, until pollen is studied at that site. Pollen and charcoal data from two other sites provided information from high-elevation forests (see Fig.1). Lost Trail Pass Bog (45.693°N, 113.953° W; 2154 m elevation) lies in the Bitterroot Range near the Continental Divide in subalpine forest of *Abies bifolia*, *Picea engelmannii*, and *Pinus contorta*. Older less-developed charcoal analysis methods were used for the Mehringer et al. (1977) study and those results cannot be compared directly to these results. Burnt Knob Lake (45.7044° N, 114.9867° W, 2250 m elevation) in the Clearwater Range, Idaho lies in forest composed of *Abies bifolia* (Rocky Mountain Subalpine Fir), *Pinus albicaulis* (Whitebark Pine) and *Pinus contorta* (Lodgepole Pine) (Brunelle et al., 2005). Charcoal analysis methods for this study are outlined in Brunelle et al. 2005.

### Late Glacial Period >11000 cal yr BP

Paleoclimate model simulations of 14,000 cal yr BP indicate that a shrinking Laurentide ice sheet coupled with rising summer insolation led to warming in the Northern Rocky Mountains compared with full-glacial conditions (Bartlein et al., 1998).

At 14,000 cal yr BP, the North American jet stream was located south of its present position, reducing winter precipitation, and summer insolation values were 6% higher than present (Bartlein et al., 1998). Conditions were warm and dry as compared to present-day conditions.

The late-glacial pollen data (>11,000 cal yr BP) from Pintlar Lake indicate that low elevations in the Big Hole region supported subalpine parkland composed of *Picea*, *Artemisia*, *Poaceae* and some *Pinus* (Fig. 4.5). The new fire reconstruction suggests that fire-episode frequency was low at both Pintlar and Reservoir lakes (Fig. 4.4). At 13,000 cal yr BP, vegetation shifted at Pintlar Lake from subalpine parkland to more closed forest dominated by *Pinus*. At high elevations, a similar vegetation change from *Picea* parkland to closed pine forests at 13,000 cal yr BP is documented at Burnt Knob Lake (Brunelle et al., 2005).

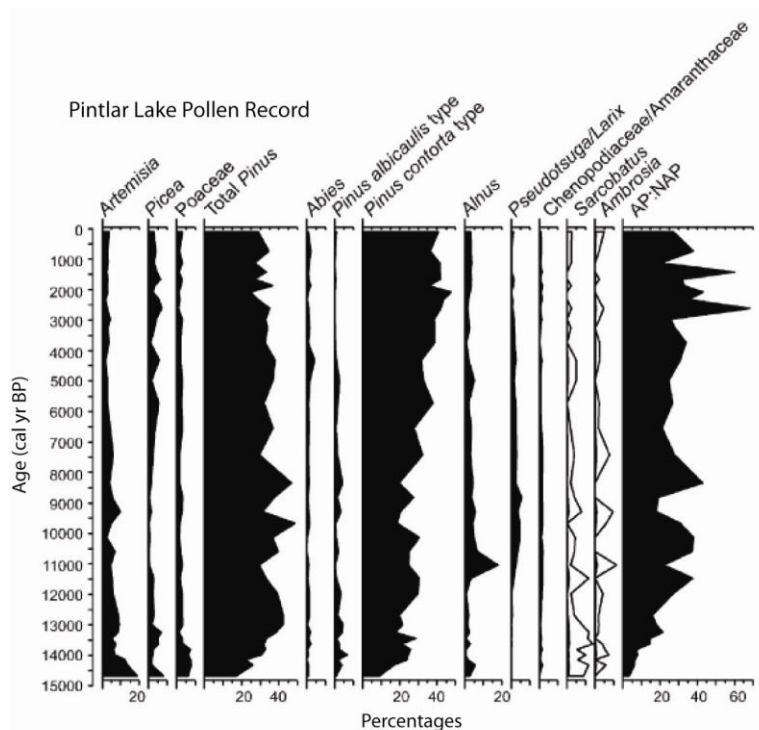


Figure 4.5. Pollen record from Pintlar Lake. Adapted from Brunelle et al. (2005).

By 13,000 cal yr BP, high *Pinus contorta*-type pollen at Pintlar Lake and elevated fire-episode frequency suggest that an increase in woody fuels (more pine) , probably as a result of warmer-than-before summer conditions. The forests at Pintlar Lake were composed of *Pinus contorta* and *Pinus albicaulis* until 12,900 cal yr BP after which, *Pinus contorta* increased and *Pinus albicaulis* decreased. Fire-episode frequency decreased after 12,800 cal yr BP at Pintlar Lake and remained steady at Reservoir Lake (Fig. 4.4 A and C). Although fire-episode frequency remained steady at Reservoir Lake on centennial time scales, the number of fire episodes that occurred was reduced (Fig. 4.6). This period of moderate fire activity at both sites lasted until 11,500 cal yr BP and corresponds in time with the Younger Dryas cold event (12,800 – 11,500 cal yr BP; Alley et al., 1993) described in Europe and the North Atlantic. Cooler regional climate conditions during the YD period have also been identified from proxy records in Colorado (12900 cal yr BP – 11700 cal yr BP; Reasoner and Jodry, 2000) and Oregon (13000 – 10900 cal yr BP; Briles et al., 2005). It is likely that drier or cooler conditions are responsible for the lower fire activity noted at Reservoir and Pintlar lakes at this time.

#### Early Holocene Period (11,000 – 6000 cal yr BP)

By 11,000 cal yr BP, the Laurentide ice sheet had decreased to 30% of its full glacial extent and summer insolation was 8% higher than present day values (Bartlein et al., 1998). One effect of higher-than-present summer insolation was a strengthened northeastern Pacific subtropical high over the Pacific Ocean and stronger-than-present

monsoonal circulation in the southwestern US, enhancing summer-wet and summer-dry precipitation regimes (Bartlein et al., 1998). The overall climate was characterized by enhanced summer-wet and summer-dry precipitation regime.

The early-Holocene vegetation history at Pintlar Lake shows characteristics of a “summer-dry” site (Brunelle et al., 2005). Following an upward shift in treeline in the late-glacial period, the pollen data indicate the development of *Pinus contorta* forest. In the early Holocene (11,000 cal yr BP), *Pinus contorta* forest was replaced by a mixed forest of *Pinus contorta* and *Pseudotsuga* (Brunelle et al., 2005), with steppe vegetation nearby. The expansion of *Pseudotsuga* at this time is noted at high elevations as well (Brunelle et al., 2005; Mehringer et al., 1977; Whitlock, 1993), and it is attributed to warmer conditions, which allowed xerophytic taxa to extend their ranges upslope. After 8000 cal yr BP, the pollen record from Pintlar Lake suggests a shift from a forest of *Pinus contorta* and *Pseudotsuga* and steppe vegetation to one composed of *Pinus contorta*, with some *Picea* and *Abies* and *Alnus* in an expanding riparian zone. This shift marks the beginning of cooler conditions than before in the middle and late Holocene.

At Reservoir Lake, a peak in fire-episode frequency at 10,500 cal yr BP was followed by a decline to a low at 7000 cal yr BP (Fig. 4.6). This signal is typical of a summer-dry site in which high fire activity is a result of dry conditions with the expansion of the subtropical high pressure system during the early-Holocene summer insolation maxima. It was followed by a decrease in fire activity as summers became wetter than before.

At Pintlar Lake, the opposite trend occurred with low fire frequencies rising from 11,000 cal yr BP ( 7 episodes/1000 years) to 9000 cal yr BP, followed by high values at 6000 cal yr BP ( 20 episodes/1000 years). This trend is consistent with summer-wet regions, where increased summer precipitation from strengthened monsoon circulation in the early Holocene depressed fire activity. In the middle Holocene, as monsoons weakened, drier-than-before summers led to more fire activity. Differences in the early-Holocene fire history response between closely spaced sites have been noted elsewhere in the Rocky Mountain region (Millspaugh et al., 2004), and seem to reflect the heterogeneity of precipitation regimes in a complex landscape (Shafer et al., 2005).

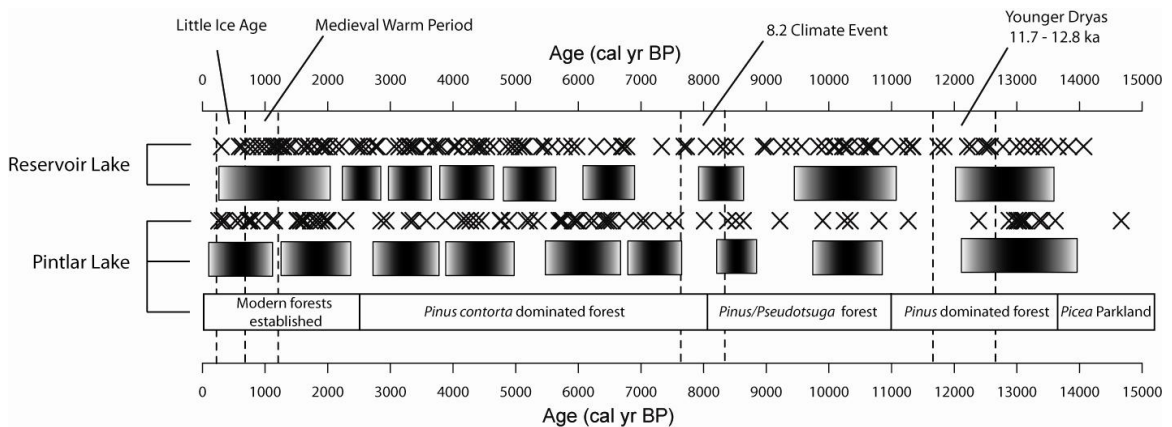


Figure 4.6. Simplified patterns of fire activity at Reservoir and Pintlar lakes. X marks indicate identified charcoal peaks in the sediment record. Boxes denote periods of high fire activity. The forest composition is inferred from pollen data at Pintlar Lake (Brunelle et al. (2005). Dashed lines indicate climate events mentioned in text.

A widely observed cool period known as the 8200-year event lasted approximately 500 years and has been attributed to the final draining of postglacial Lake

Agassiz into the North Atlantic (Morrill and Jacobsen, 2005; Rohling and Pälike, 2005). A lake-sediment record from the Idaho-Utah border shows this event as an abrupt increase in precipitation of calcium carbonate, resulting from warmer water and increased evaporation (Dean et al., 2006). Similarly, Elk Lake in Minnesota shows rapid increases in windblown dust at this time that have been attributed to cooler conditions and more open vegetation (Dean et al, 2002). Fire frequency data at Reservoir and Pintlar lakes do not show an abrupt change at this time, although there does appear to be a slight decrease in the occurrence of fire episodes at this time (Fig 4.6).

#### Middle Holocene Period (6000 – 2500 cal yr BP)

At 6000 cal yr BP, Northern Hemisphere ice sheets were near present-day size and summer insolation was 6% higher than current values (Kutzbach et al., 1998). Climate models for this period indicate that summer precipitation was lower in summer-dry areas and higher in summer-wet areas (Harrison et al., 2003). During this time period, summer-wet and summer-dry contrasts were weakening as compared to the previous period.

The fire frequency at Reservoir Lake increased after 7200 cal yr BP, reaching 27 episodes/1000 years at 2000 cal yr BP (Fig. 4.4), and the trend is consistent with summer-wet regions where summer precipitation decreased from the early Holocene and conditions became progressively drier. At Reservoir Lake, low fire frequency occurred ca. 7000 cal yr BP. At Pintlar Lake, fire frequency was high at 6000 cal yr BP (20 episodes/1000years), decreased to 15 episodes/1000 years at 3200 cal yr BP and

increased to 25 episodes/1000years at 2000 cal yr BP (Fig. 3.4). Brunelle et al. (2005) attribute high fire frequency at 6000 cal yr BP at Pintlar Lake to weakening monsoon precipitation in summer-wet regions.

#### Late Holocene Period (2500 cal yr BP – present)

By 3000 cal yr BP, closed forests of *Pinus contorta* with minor amounts of *Picea* and *Abies* grew near Pintlar Lake (Brunelle et al., 2005), and this period probably marks the establishment of the modern forest-steppe ecotone around the Big Hole Valley. Reservoir Lake had the highest fire frequency of the entire record at 2000 cal yr BP, with values of >25 episodes/1000 years. Pintlar Lake shows high CHAR at 1800 cal yr BP, but values decreased at 1000 cal yr BP as did fire-episode frequency. Lost Trail Pass Bog registered high rates of charcoal accumulation throughout this period (Mehring et al., 1977), although individual fire episodes cannot be identified.

Between 5000 and 2000 cal yr BP, fire records from Pintlar and Reservoir lakes do not behave synchronously, and I suggest that this is partly a function of the greater sensitivity of new decomposition method. The decrease in charcoal peak detection at Pintlar Lake is influenced by the high CHAR between 2100 and 1400 cal yr BP. The CHAR levels clearly indicate that fire activity was high, but the signal-to-noise ratio is too low to detect significant peaks. Reservoir Lake does not show similar variations in CHAR, and as a result, the fire-episode frequency is probably more accurately reconstructed at that site. The steady rise in fire frequencies at Reservoir Lake through the late Holocene

is typical of summer-wet regions, and it suggests a long-term decline in summer precipitation in recent millennia.

During the late Holocene, proxy records from the western US show drier conditions during the Medieval Climate Anomaly (MCA, 1150 – 650 cal yr BP; Cronin et al., 2003; Pierce et al., 2004) and cooler/wetter conditions during the Little Ice Age (LIA, 750 – 50 cal yr BP; Carrara and McGimsey, 1981; Luckman et al., 1993; Meyer and Pierce, 2003). Meyer and Pierce (2003) observed an increase in fire-related debris flows during the MCA where in Yellowstone National Park and more fires were recorded at Reservoir Lake and at Burnt Knob Lake (Brunelle and Whitlock, 2003). Lost Trail Pass Bog also registered a significant input of charcoal, which was attributed to increased anthropogenic burning (Mehring et al., 1977), but probably also reflects drier conditions in the MCA.

During the LIA, glaciers in the Northern Rocky Mountains reached their maximum extent since the late Pleistocene (Carrara and McGimsey, 1981; Luckman et al., 1993). Meyer and Pierce (2003) found a reduction in the magnitude of fire-related debris flows during the Little Ice Age (LIA). Burnt Knob Lake shows a slight decrease in fire frequency during this time (Brunelle et al., 2005), whereas Lost Trail Pass Bog indicates higher charcoal values in the later part of the record (Mehring et al., 1977). At Reservoir Lake there also appear to be a reduction in fires during the LIA (Fig. 4.6).

### Conclusions

A high-resolution charcoal record was constructed from Reservoir Lake to examine variations in fire activity during the late-glacial and Holocene periods. Examination of the Reservoir Lake charcoal data and their comparison with other paleoclimatic proxy and paleoclimatic model simulations provide better understanding of the climate, vegetation and fire interactions in the Northern Rocky Mountains. Re-analysis of the Pintlar Lake charcoal record using a new chronology and new statistical analyses revealed slightly different patterns than described in Brunelle et al. (2005) and altered to some degree the original interpretation, as described below. The fire-episode frequency reconstruction was generally similar at Reservoir and Pintlar lakes and both reconstructions shared common features with the fire histories from nearby high-elevation sites, Lost Trail Pass Bog and Burnt Knob Lake.

In the late-glacial period prior to 11000 cal yr BP, fires were infrequent at both sites as a result of sparse vegetation cover and cool conditions. Increased summer insolation during the early-Holocene period and warmer temperatures, led to longer growing seasons in the region and this is manifest as an upward shift in upper treeline at Burnt Knob Lake. At the same time, there was more *Pseudotsuga* than at present near Lost Trail Pass Bog. Warmer, effectively drier conditions in the early Holocene are also evidenced by the high fire activity at Reservoir Lake, consistent with a summer-dry precipitation region. At Pintlar Lake, fire frequency was relatively low in the early Holocene and reached a maximum at 6000 years. This pattern is consistent with the

climate history at other summer-wet sites in the Northern Rocky Mountains and Yellowstone, which were influenced by a stronger-than-present summer monsoon in the early Holocene. The contrast between the two records suggests that summer-wet vs. summer-dry patterns were evident during this time period.

After 6000 cal yr BP, the fire records from Reservoir and Pintlar lakes show responses that are more typical of summer-wet regions with increasing fire activity in the middle and late Holocene. At Reservoir Lake, fire activity is highest during the Medieval Climate Anomaly (MCA, 1150 – 650 cal yr BP; Cronin et al., 2003; Pierce et al., 2004) and decreases during the Little Ice Age (750 – 50 cal yr BP; Carrara and McGimsey, 1981; Luckman et al., 1993; Meyer and Pierce, 2003) . At Pintlar Lake, fire activity is elevated during the MCA and decreases to the present day with no significant change during the Little Ice Age.

The fire-climate linkages observed in the paleoecological record provide insights that are useful in understanding future fire regimes with projected climate changes. Temperatures in the western US have increased significantly in recent decades. In western Montana, average temperatures over the last four years (2003 - 2007) are 1.1°C higher than average values observed during the 20<sup>th</sup> century (Saunders et al., 2008). The effects of warmer winter and spring temperatures have resulted in increased fire frequency and a longer fire season in the western US (Westerling et al., 2006). Future climate projections indicate that portions of the Northern Rocky Mountains could experience an increase in mean annual temperatures of 3.2°C by 2070 and 6°C by the

end of the century (CMIP3 data, 2007). The results from this study indicate that warmer drier conditions in the early Holocene resulted in a small increase in fire activity between 11,000 and 9500 cal yr BP. The highest fire frequency occurred from 6000 to 1500 cal yr BP, suggesting increased aridity in the middle and late Holocene. If the response to warm dry conditions during the Holocene can serve as an analogue for future conditions, more frequent burning is likely in the future in the Northern Rocky Mountains.

### References Cited

Bartlein, P. J., Anderson, K. H., Anderson, P. M., Edwards, M. E., Mock, C. J., Thompson, R. S., Webb, R. S., Webb lii, T., and Whitlock, C. (1998). Paleoclimate simulations for North America over the past 21,000 years features of the simulated climate and comparisons with paleoenvironmental data. *Quaternary Science Reviews* 17, 549-585.

Biondi, F., Perkins, D.L., Cayan, D.R., Hughes, M.K. (1999). July Temperature During the Second Millennium Reconstructed from Idaho Tree Rings. *Geophysical Research Letters* 26, 1445-1448

Boerner, R. E. J. (1982). Fire and Nutrient Cycling in Temperate Ecosystems. *BioScience* 32, 187-192.

Briles, C. E., Whitlock, C., and Bartlein, P.J. (2005). Postglacial Vegetation, Fire, and Climate History of the Siskiyou Mountains, Oregon, USA. *Quaternary Research* 64, 44-56.

Brown, James K.; Smith, Jane Kapler, eds. (2000). *Wildland fire in ecosystems: effects of fire on flora*. Gen. Tech. Rep. RMRS-GTR-42-vol. 2. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 257 p.

Brunelle, A., and Whitlock, C. (2003). Postglacial fire, vegetation, and climate history in the Clearwater Range, Northern Idaho, USA. *Quaternary Research* 60, 307-318.

Brunelle, A., Whitlock, C., Bartlein, P., and Kipfmueeller, K. (2005). Holocene fire and vegetation along environmental gradients in the Northern Rocky Mountains. *Quaternary Science Reviews* 24, 2281-2300.

Campbell, C. (1998). Late Holocene Lake Sedimentology and Climate Change in Southern Alberta, Canada. *Quaternary Research* 49, 96-101.

Carrara, P. E., and McGimsey, R. G. (1981). The Late-Neoglacial Histories of the Agassiz and Jackson Glaciers, Glacier National Park, Montana. *Arctic and Alpine Research* 13, 183-196.

CMIP climate data. World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset. available online: [http://gdo-dcp.ucllnl.org/downscaled\\_cmip3\\_projections/#Welcome](http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/#Welcome)

- Clark, J. S., Royall, P. D., and Chumbley, C. (1996). The Role of Fire During Climate Change in an Eastern Deciduous Forest at Devil's Bathtub, New York. *Ecology* 77, 2148-2166.
- Cook, E. R., Woodhouse, C. A., Eakin, C. M., Meko, D. M., and Stahle, D. W. (2004). Long-Term Aridity Changes in the Western United States. *Science* 306, 1015-1018.
- Cronin, T. M., Dwyer, G. S., Kamiya, T., Schwede, S., and Willard, D. A. (2003). Medieval Warm Period, Little Ice Age and 20th century temperature variability from Chesapeake Bay. *Global and Planetary Change* 36, 17-29.
- Dean, W. (2002). A 1500-year record of climatic and environmental change in Elklake, Clearwater County, Minnesota II: geochemistry, mineralogy, and stable isotopes. *Journal of Paleolimnology* 27, 301-319.
- Dean, W., Rosenbaum, J., Skipp, G., Colman, S., Forester, R., Liu, A., Simmons, K., and Bischoff, J. (2006). Unusual Holocene and late Pleistocene carbonate sedimentation in Bear Lake, Utah and Idaho, USA. *Sedimentary Geology* 185, 93-112.
- Gavin, D. G., Hu, F. S., Lertzman, K., and Corbett, P. (2006). Weak climatic control of stand-scale fire history during the late Holocene. *Ecology* 87, 1722-1732.
- Hallett, D. J., Hills, L. V., and Clague, J. J. (1997). New accelerator mass spectrometry radiocarbon ages for the Mazama tephra layer from Kootenay National Park, British Columbia, Canada. *Canadian Journal of Earth Sciences* 34, 1202-1209.
- Harrison, S. P., Kutzbach, J. E., Liu, Z., Bartlein, P. J., Otto-Bliesner, B., Muhs, D., Prentice, I. C., and Thompson, R. S. (2003). Mid-Holocene climates of the Americas: a dynamical response to changed seasonality. *Climate Dynamics* 20, 663-688.
- Higuera, P. E., Peters, M. E., Brubaker, L. B., and Gavin, D. (2007). Understanding the origin and analysis of sediment-charcoal records with a 1 simulation model 2. *Quaternary Science Reviews*.
- Kutzbach, J., Gallimore, R., Harrison, S., Behling, P., Selin, R., and Laarif, F. (1998). Climate and biome simulations for the past 21,000 years. *Quaternary Science Reviews* 17, 473-506.
- Locke, W. W. (1990). Late Pleistocene Glaciers and the Climate of Western Montana, USA. *Arctic and Alpine Research* 22, 1-13.

- Long, C. J., Whitlock, C., Bartlein, P.J., and Millspaugh, S.H. (1998). A 9000-Year Fire History From the Oregon Coast Range, Based on High-Resolution Charcoal Study. *Canadian Journal of Forest Research* 28, 774-787.
- Luckman, B. H., Holdsworth, G., and Osborn, G. D. (1993). Neoglacial glacier fluctuations in the Canadian Rockies. *Quaternary Research* 39, 144-153.
- Lyford, M. E., Jackson, S. T., Betancourt, J. L., and Gray, S. T. (2003). Influence of landscape structure and climate variability on a late Holocene plant migration. *Ecological Monographs* 73, 567-583.
- Mehring Jr, P. J., Arno, S. F., and Petersen, K. L. (1977). Postglacial History of Lost Trail Pass Bog, Bitterroot Mountains, Montana. *Arctic and Alpine Research* 9, 345-368.
- Meyer, G. A., and Pierce, J. L. (2003). Climatic controls on fire-induced sediment pulses in Yellowstone National Park and central Idaho: a long-term perspective. *Forest Ecology and Management* 178, 89-104.
- Millsaugh, S. H., and Whitlock, C. (2004). Postglacial Fire, Vegetation, and Climate History of the Yellowstone-Lamar and Central Plateau Provinces, Yellowstone. *After the Fires: The Ecology of Change in Yellowstone National Park*.
- Millsaugh, S. H., Whitlock, C., and Bartlein, P. J. (2000). Variations in fire frequency and climate over the past 17 000 yr in central Yellowstone National Park. *Geology* 28, 211-214.
- Mock, C. J. (1996). Climatic Controls and Spatial Variations of Precipitation in the Western United States. *Journal of Climate* 9, 1111-1125.
- Morrill, C., and Jacobsen, R. M. (2005). How widespread were climate anomalies 8200 years ago. *Geophysical Research Letters* 32.
- Pederson, G. T., Fagre, D. B., Gray, S. T., and Graumlich, L. J. (2004). Decadal-scale climate drivers for glacial dynamics in Glacier National Park, Montana, USA. *GEOPHYSICAL RESEARCH LETTERS* 31, L12203.
- Power, M. J., Whitlock, C., Bartlein, P., and Stevens, L.R. (2006). Fire and vegetation history during the last 3800 years in northwestern Montana. *Geomorphology* 75, 420-436.
- PRISM climate group. (2008). Available online <http://www.prism.oregonstate.edu/>

- Pierce, J. L., Meyer, G. A., and Jull, A. J. (2004). Fire-induced erosion and millennial-scale climate change in northern ponderosa pine forests. *Nature* 432, 87-90.
- Power, M. J., Whitlock, C., Bartlein, P., and Stevens, L. R. (2006). Fire and vegetation history during the last 3800 years in northwestern Montana. *Geomorphology* 75, 420-436.
- R Core Development Team. (2008) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.
- Reasoner, M. A., and Jodry, M. A. (2000). Rapid response of alpine timberline vegetation to the Younger Dryas climate oscillation in the Colorado Rocky Mountains, USA. *Geology* 28, 51-54.
- Rohling, E. J., and Paelike, H. (2005). Centennial-scale climate cooling with a sudden cold event around 8, 200 years ago. *Nature* 434, 975-979.
- Saunders, S., Montgomery, C., and Easley, T. (2008). Hotter and Drier. The West's Changed Climate. The Rocky Mountain Climate Organization. Available online <http://www.rockymountainclimate.org/>
- Shafer, S. L., Bartlein, P. J., and Whitlock, C. (2005). Understanding the Spatial Heterogeneity of Global Environmental Change in Mountain Regions. *Global Change and Mountain Regions: An Overview of Current Knowledge*.
- Stuvier, M., Reimer, P. J., Bard, E., Beck, J. W., Burr, G. S., Hughen, K. A., Kromer, B., McCormac, F. G., Plicht, J., and Spurk, M. (1998). INTCAL98 Radiocarbon calibration. *Radiocarbon* 40, 1041-1083.
- Westerling, A. L., Hidalgo, H. G., Cayan, D. R., and Swetnam, T. W. (2006). Warming and earlier spring increase western US forest wildfire activity. *Science* 313, 940-943.
- Whitlock, C. (1993). Postglacial Vegetation and Climate of Grand-Teton and Southern-Yellowstone-National-Parks. *Ecological Monographs* 63, 173-198.
- Whitlock, C., and Bartlein, P. J. (1993). Spatial variations of Holocene climatic change in the Yellowstone region. *Quaternary Research* 39, 231-238.
- Whitlock, C., and Larsen, C. (2001). Charcoal as a fire proxy. *Tracking environmental change using lake sediments* 3, 75-97.

Whitlock, C., and Millspaugh, S. H. (1996). Testing the assumptions of fire-history studies: an examination of modern charcoal accumulation in Yellowstone National Park, USA. *The Holocene* 6, 7.

Whitlock, C., Shafer, S. L., and Marlon, J. (2003). The role of climate and vegetation change in shaping past and future fire regimes in the northwestern US and the implications for ecosystem management. *Forest Ecology and Management* 178, 5-21.

Wright Jr, H. E., Mann, D. H., and Glaser, P. H. (1984). Piston Corers for Peat and Lake Sediments. *Ecology* 65, 657-659.

## CHAPTER 5

## CONCLUSIONS

This thesis examined forest disturbance history on centennial and millennial time scales. In order to test if lake sediments record past infestations of mountain pine beetle, sediments were sampled from small lakes in the Sawtooth Mountains, Idaho, where severe infestations of mountain pine beetle have recently taken place. Two other chapters of the thesis reconstructed fire histories from the Sawtooth Mountains, Idaho, and the Beaverhead Range, Montana to better understand variations in forest fire activity on centennial and millennial time scales.

Long-term variations in mountain pine beetle outbreaks are poorly understood. This is due to the fact that records extending outside the range of historical data are rare. The studies that have attempted to reconstruct past mountain pine beetle outbreaks make many assumptions without fully understanding if and how beetle remains would be incorporated into lake-sediment sequences. Chapter 2 of this thesis outlines the study I undertook to better understand if mountain pine beetle remains accumulate in lake sediments following an outbreak. The results from this study suggest that, in the years following an outbreak, there is no large influx of mountain pine beetle remains into sedimentary sequences. The scarcity of insect remains could be because a) not enough time has passed for the insect remains to have washed into the lakes, or b) lake sediments do not preserve the remains of mountain pine beetle. A future study in the next 5-10 years might effectively test these alternative hypotheses.

In chapter 3 of this thesis, the objective was to reconstruct fire history over the last 2000 years in the Sawtooth Mountains, Idaho. High-resolution charcoal analysis was undertaken at three lakes in lodgepole pine forest to better understand the environmental history in central Idaho. Results from this chapter suggest that climate variations of the magnitudes of the Medieval Climate Anomaly and Little Ice Age did not change the fire frequency of the surrounding forests. This study investigated only three sites from the Sawtooth Mountains and additional lake-sediment records will help determine how fire regimes respond to long-term climate changes in the area.

Chapter 4 of this thesis investigates fire history over the last 15,000 years in the Beaverhead Range, southwestern Montana. A high-resolution charcoal record was studied at Reservoir Lake located at the lower forest steppe border to compare the fire history with other paleoenvironmental records from the region. The fire-episode frequency reconstruction was generally similar to a record from a nearby low-elevation site, Pintlar Lake, and it shared features with the charcoal records from nearby high-elevation sites, Lost Trail Pass Bog and Burnt Knob Lake. The fire-climate linkages observed in the paleoecological record provide insights that are useful in understanding future fire regimes with projected climate changes. As more records with a similar high resolution become available, we will better understand the spatial and temporal variations in postglacial fire history in the region.

This thesis research is important for a number of reasons. First, Chapter 2's investigation of lake sediment response to mountain pine beetle outbreaks provides a

framework for understanding if and how lake sediments could be used to reconstruct longer records of mountain pine beetle infestation. Second, Chapter 3 provides the first fire-history information from the Sawtooth Mountains, Idaho. This pilot study provides baseline information from which to undertake a more spatially robust investigation of the fire history of the last 2000 years. The importance of the Chapter 4 is its presentation of high-quality fire-history data from the lower forest steppe, an area that has been little studied. The charcoal record from Reservoir Lake helps us better understand the long-term fire history at low elevations and offers a benchmark for future studies in the area.

## APPENDICES

APPENDIX A

IMPORTANT COMMUNICATION IN REGARDS TO THESIS

Communication with Ryan Bracewell

5/15/2008

Hello Josh,

Jim Vandygriff forwarded me your message and link to the photos. I have a little more experience looking at different species of bark beetles than he does, but am by no means an expert taxonomist and coleopterist. However, my limited experience would suggest that any identifications from your parts would be difficult at best, and nearly impossible with the photos. You do seem to have a few preserved elytra, (although I don't think they look like anything from Scolytidae), and a few other parts that someone could get to order, and possibly family. I think I did ID an ant head (or some hymenoptera thing for that matter ), with missing antennae and eyes (photo attached of your pic and one of an ant that I pulled off of internet for comparison). Unfortunately many diagnostic characters on insects will be missing if you only have parts, and it would be hard to get much better than an insect family. If all you care about is trying to identify scolytids, then Donald Bright at Colorado State might be able to help and tell you what is definitely not a scolytid. I would be a little cautious in anticipating finding many scolytids since there are so many other beetles (let alone insects) that could find their way into your samples.

All the best,

Ryan

Communication with Donald Bright

6/13/2008

Josh:

I received your e-mail with the images and the later e-mails. Sorry to be so long in answering, no excuse, just busy.

I have looked again at the images and the only ones I could identify as possibly a scolytid are:

bhl\_b\_02... = Dendroctonus pronotum  
ch2\_sc\_192 ...= possibly a scolytid but can't be sure  
mth\_a\_24... = Dendroctonus elytron  
mth\_b\_02... = Possibly a Dendroctonus head  
runelk\_a\_24... = Dendroctonus elytron

All the rest are pieces that I do not recognize. In many cases, the light reflection makes it very difficult to see the features.

I'm afraid I was not of much help, but maybe something can be gleaned from these results.

Best wishes,  
D. E. Bright

Dr. Donald E. Bright  
C. P. Gillette Museum of Arthropod Diversity  
Dept. of Bioagriculture Sciences & Pest Management  
Colorado State University,  
Fort Collins, Colorado 80523  
Phone (970) 491-0490  
e-mail: [dbright@mail.colostate.edu](mailto:dbright@mail.colostate.edu)

Communication with Wyatt Cross

6/8/2008

Hi Josh,

I'd be happy to meet with you sometime to discuss. Unfortunately, I will be in the field for the rest of this month. Can we meet in early July? My knee-jerk reaction is that if huge amounts of pine beetles washed into (and settled in) lakes, you should see some remains. There are certainly predatory insects in these lakes, but the exoskeletons of those beetles are pretty resistant to consumption and digestion. Get back in touch in July if you want to chat then.

Wyatt

---

Wyatt F. Cross  
Assistant Professor  
Department of Ecology  
Montana State University  
Bozeman, MT 59717

APPENDIX B

RAW CHARCOAL COUNTS

## Raw Charcoal data from Cape Horn II Lake

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 0.00                | -54             | 1                                | 2                            |
| 0.50                | -49             | 1                                | 4                            |
| 1.00                | -44             | 1                                | 6                            |
| 1.50                | -40             | 1                                | 5                            |
| 2.00                | -36             | 1                                | 4                            |
| 2.50                | -32             | 1                                | 14                           |
| 3.00                | -29             | 1                                | 6                            |
| 3.50                | -27             | 1                                | 6                            |
| 4.00                | -24             | 1                                | 10                           |
| 4.50                | -22             | 1                                | 7                            |
| 5.00                | -20             | 1                                | 7                            |
| 5.50                | -17             | 1                                | 1                            |
| 6.00                | -15             | 1                                | 9                            |
| 6.50                | -13             | 1                                | 3                            |
| 7.00                | -10             | 1                                | 1                            |
| 7.50                | -7              | 1                                | 5                            |
| 8.00                | -4              | 1                                | 2                            |
| 8.50                | -2              | 1                                | 11                           |
| 9.00                | 1               | 1                                | 6                            |
| 9.50                | 4               | 1                                | 5                            |
| 10.00               | 7               | 1                                | 4                            |
| 10.50               | 9               | 1                                | 5                            |
| 11.00               | 12              | 1                                | 7                            |
| 11.50               | 14              | 1                                | 6                            |
| 12.00               | 17              | 1                                | 12                           |
| 12.50               | 19              | 1                                | 1                            |
| 13.00               | 22              | 1                                | 2                            |
| 13.50               | 24              | 1                                | 3                            |
| 14.00               | 26              | 1                                | 6                            |
| 14.50               | 29              | 1                                | 7                            |
| 15.00               | 31              | 1                                | 6                            |
| 15.50               | 34              | 1                                | 9                            |
| 16.00               | 36              | 1                                | 14                           |
| 16.50               | 39              | 1                                | 11                           |
| 17.00               | 41              | 1                                | 14                           |
| 17.50               | 44              | 1                                | 7                            |
| 18.00               | 47              | 1                                | 9                            |
| 18.50               | 50              | 1                                | 9                            |
| 19.00               | 53              | 1                                | 5                            |
| 19.50               | 56              | 1                                | 4                            |
| 20.00               | 59              | 1                                | 4                            |
| 20.50               | 63              | 1                                | 4                            |
| 21.00               | 66              | 1                                | 4                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 21.50               | 70              | 1                                | 7                            |
| 22.00               | 74              | 1                                | 9                            |
| 22.50               | 78              | 1                                | 3                            |
| 23.00               | 82              | 1                                | 8                            |
| 23.50               | 86              | 1                                | 7                            |
| 24.00               | 90              | 1                                | 3                            |
| 24.50               | 94              | 1                                | 3                            |
| 25.00               | 99              | 1                                | 6                            |
| 25.50               | 104             | 1                                | 7                            |
| 26.00               | 109             | 1                                | 2                            |
| 26.50               | 114             | 1                                | 3                            |
| 27.00               | 119             | 1                                | 2                            |
| 27.50               | 124             | 1                                | 4                            |
| 28.00               | 130             | 1                                | 6                            |
| 28.50               | 135             | 1                                | 8                            |
| 29.00               | 141             | 1                                | 6                            |
| 29.50               | 147             | 1                                | 3                            |
| 30.00               | 153             | 1                                | 7                            |
| 30.50               | 159             | 1                                | 13                           |
| 31.00               | 166             | 1                                | 1                            |
| 31.50               | 172             | 1                                | 3                            |
| 32.00               | 178             | 1                                | 5                            |
| 32.50               | 186             | 1                                | 3                            |
| 33.00               | 194             | 1                                | 3                            |
| 33.50               | 202             | 1                                | 2                            |
| 34.00               | 210             | 1                                | 2                            |
| 34.50               | 218             | 1                                | 10                           |
| 35.00               | 225             | 1                                | 14                           |
| 35.50               | 233             | 1                                | 5                            |
| 36.00               | 241             | 1                                | 8                            |
| 36.50               | 249             | 1                                | 4                            |
| 37.00               | 257             | 1                                | 1                            |
| 37.50               | 265             | 1                                | 10                           |
| 38.00               | 273             | 1                                | 3                            |
| 38.50               | 280             | 1                                | 3                            |
| 39.00               | 288             | 1                                | 11                           |
| 39.50               | 296             | 1                                | 7                            |
| 40.00               | 304             | 1                                | 5                            |
| 40.50               | 312             | 1                                | 7                            |
| 41.00               | 320             | 1                                | 5                            |
| 41.50               | 327             | 1                                | 7                            |
| 42.00               | 335             | 1                                | 10                           |
| 42.50               | 343             | 1                                | 11                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 43.00               | 351             | 1                                | 9                            |
| 43.50               | 359             | 1                                | 10                           |
| 44.00               | 367             | 1                                | 9                            |
| 44.50               | 375             | 1                                | 12                           |
| 45.00               | 382             | 1                                | 6                            |
| 45.50               | 390             | 1                                | 7                            |
| 46.00               | 398             | 1                                | 5                            |
| 46.50               | 406             | 1                                | 9                            |
| 47.00               | 414             | 1                                | 2                            |
| 47.50               | 422             | 1                                | 12                           |
| 48.00               | 430             | 1                                | 4                            |
| 48.50               | 437             | 1                                | 5                            |
| 49.00               | 445             | 1                                | 7                            |
| 49.50               | 453             | 1                                | 10                           |
| 50.00               | 461             | 1                                | 4                            |
| 50.50               | 469             | 1                                | 3                            |
| 51.00               | 477             | 1                                | 7                            |
| 51.50               | 484             | 1                                | 10                           |
| 52.00               | 492             | 1                                | 10                           |
| 52.50               | 500             | 1                                | 11                           |
| 53.00               | 508             | 1                                | 11                           |
| 53.50               | 516             | 1                                | 15                           |
| 54.00               | 524             | 1                                | 8                            |
| 54.50               | 532             | 1                                | 11                           |
| 55.00               | 539             | 1                                | 9                            |
| 55.50               | 547             | 1                                | 12                           |
| 56.00               | 555             | 1                                | 10                           |
| 56.50               | 563             | 1                                | 8                            |
| 57.00               | 571             | 1                                | 3                            |
| 57.50               | 579             | 1                                | 8                            |
| 58.00               | 586             | 1                                | 12                           |
| 58.50               | 594             | 1                                | 5                            |
| 59.00               | 602             | 1                                | 5                            |
| 59.50               | 610             | 1                                | 4                            |
| 60.00               | 618             | 1                                | 8                            |
| 60.50               | 626             | 1                                | 11                           |
| 61.00               | 634             | 1                                | 15                           |
| 61.50               | 641             | 1                                | 13                           |
| 62.00               | 649             | 1                                | 19                           |
| 62.50               | 657             | 1                                | 11                           |
| 63.00               | 665             | 1                                | 12                           |
| 63.50               | 673             | 1                                | 16                           |
| 64.00               | 681             | 1                                | 6                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 64.50               | 689             | 1                                | 7                            |
| 65.00               | 696             | 1                                | 10                           |
| 65.50               | 704             | 1                                | 7                            |
| 66.00               | 712             | 1                                | 9                            |
| 66.50               | 720             | 1                                | 10                           |
| 67.00               | 728             | 1                                | 9                            |
| 67.50               | 736             | 1                                | 16                           |
| 68.00               | 743             | 1                                | 9                            |
| 68.50               | 751             | 1                                | 11                           |
| 69.00               | 759             | 1                                | 10                           |
| 69.50               | 767             | 1                                | 12                           |
| 70.00               | 775             | 1                                | 11                           |
| 70.50               | 783             | 1                                | 18                           |
| 71.00               | 791             | 1                                | 17                           |
| 71.50               | 798             | 1                                | 16                           |
| 72.00               | 806             | 1                                | 18                           |
| 72.50               | 814             | 1                                | 12                           |
| 73.00               | 822             | 1                                | 12                           |
| 73.50               | 830             | 1                                | 13                           |
| 74.00               | 838             | 1                                | 21                           |
| 74.50               | 845             | 1                                | 10                           |
| 75.00               | 853             | 1                                | 11                           |
| 75.50               | 861             | 1                                | 12                           |
| 76.00               | 869             | 1                                | 9                            |
| 76.50               | 877             | 1                                | 10                           |
| 77.00               | 885             | 1                                | 10                           |
| 77.50               | 893             | 1                                | 14                           |
| 78.00               | 900             | 1                                | 10                           |
| 78.50               | 908             | 1                                | 23                           |
| 79.00               | 916             | 1                                | 17                           |
| 79.50               | 924             | 1                                | 14                           |
| 80.00               | 932             | 1                                | 11                           |
| 80.50               | 940             | 1                                | 12                           |
| 81.00               | 948             | 1                                | 20                           |
| 81.50               | 955             | 1                                | 4                            |
| 82.00               | 963             | 1                                | 13                           |
| 82.50               | 971             | 1                                | 7                            |
| 83.00               | 979             | 1                                | 8                            |
| 83.50               | 987             | 1                                | 8                            |
| 84.00               | 995             | 1                                | 15                           |
| 84.50               | 1002            | 1                                | 19                           |
| 85.00               | 1010            | 1                                | 26                           |
| 85.50               | 1018            | 1                                | 24                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 86.00               | 1026            | 1                                | 23                           |
| 86.50               | 1034            | 1                                | 21                           |
| 87.00               | 1042            | 1                                | 24                           |
| 87.50               | 1050            | 1                                | 16                           |
| 88.00               | 1057            | 1                                | 13                           |
| 88.50               | 1065            | 1                                | 16                           |
| 89.00               | 1073            | 1                                | 9                            |
| 89.50               | 1081            | 1                                | 12                           |
| 90.00               | 1089            | 1                                | 19                           |
| 90.50               | 1097            | 1                                | 19                           |
| 91.00               | 1105            | 1                                | 20                           |
| 91.50               | 1112            | 1                                | 12                           |
| 92.00               | 1120            | 1                                | 18                           |
| 92.50               | 1128            | 1                                | 11                           |
| 93.00               | 1136            | 1                                | 20                           |
| 93.50               | 1144            | 1                                | 11                           |
| 94.00               | 1152            | 1                                | 25                           |
| 94.50               | 1159            | 1                                | 7                            |
| 95.00               | 1167            | 1                                | 16                           |
| 95.50               | 1175            | 1                                | 14                           |
| 96.00               | 1183            | 1                                | 12                           |

## Raw Charcoal data from Hidden Lake

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 0.00                | -56             | 1                                | 3                            |
| 0.50                | -53             | 1                                | 3                            |
| 1.00                | -50             | 1                                | 7                            |
| 1.50                | -47             | 1                                | 2                            |
| 2.00                | -44             | 1                                | 5                            |
| 2.50                | -41             | 1                                | 10                           |
| 3.00                | -38             | 1                                | 5                            |
| 3.50                | -35             | 1                                | 4                            |
| 4.00                | -33             | 1                                | 5                            |
| 4.50                | -30             | 1                                | 7                            |
| 5.00                | -27             | 1                                | 6                            |
| 5.50                | -24             | 1                                | 4                            |
| 6.00                | -21             | 1                                | 6                            |
| 6.50                | -18             | 1                                | 6                            |
| 7.00                | -15             | 1                                | 4                            |
| 7.50                | -12             | 1                                | 5                            |
| 8.00                | -9              | 1                                | 9                            |
| 8.50                | -7              | 1                                | 8                            |
| 9.00                | -4              | 1                                | 6                            |
| 9.50                | -1              | 1                                | 5                            |
| 10.00               | 1               | 1                                | 10                           |
| 10.50               | 4               | 1                                | 9                            |
| 11.00               | 7               | 1                                | 5                            |
| 11.50               | 10              | 1                                | 5                            |
| 12.00               | 13              | 1                                | 6                            |
| 12.50               | 16              | 1                                | 10                           |
| 13.00               | 20              | 1                                | 4                            |
| 13.50               | 23              | 1                                | 4                            |
| 14.00               | 27              | 1                                | 5                            |
| 14.50               | 31              | 1                                | 4                            |
| 15.00               | 35              | 1                                | 2                            |
| 15.50               | 39              | 1                                | 4                            |
| 16.00               | 42              | 1                                | 4                            |
| 16.50               | 46              | 1                                | 4                            |
| 17.00               | 50              | 1                                | 6                            |
| 17.50               | 53              | 1                                | 6                            |
| 18.00               | 56              | 1                                | 8                            |
| 18.50               | 59              | 1                                | 10                           |
| 19.00               | 62              | 1                                | 3                            |
| 19.50               | 64              | 1                                | 10                           |
| 20.00               | 67              | 1                                | 3                            |
| 20.50               | 69              | 1                                | 5                            |
| 21.00               | 72              | 1                                | 6                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 21.50               | 74              | 1                                | 11                           |
| 22.00               | 76              | 1                                | 30                           |
| 22.50               | 78              | 1                                | 22                           |
| 23.00               | 80              | 1                                | 21                           |
| 23.50               | 83              | 1                                | 13                           |
| 24.00               | 86              | 1                                | 15                           |
| 24.50               | 89              | 1                                | 28                           |
| 25.00               | 92              | 1                                | 24                           |
| 25.50               | 96              | 1                                | 12                           |
| 26.00               | 100             | 1                                | 10                           |
| 26.50               | 105             | 1                                | 15                           |
| 27.00               | 110             | 1                                | 6                            |
| 27.50               | 115             | 1                                | 13                           |
| 28.00               | 121             | 1                                | 12                           |
| 28.50               | 127             | 1                                | 5                            |
| 29.00               | 133             | 1                                | 2                            |
| 29.50               | 143             | 1                                | 3                            |
| 30.00               | 152             | 1                                | 4                            |
| 30.50               | 161             | 1                                | 7                            |
| 31.00               | 171             | 1                                | 7                            |
| 31.50               | 180             | 1                                | 11                           |
| 32.00               | 190             | 1                                | 5                            |
| 32.50               | 199             | 1                                | 4                            |
| 33.00               | 209             | 1                                | 15                           |
| 33.50               | 218             | 1                                | 14                           |
| 34.00               | 228             | 1                                | 7                            |
| 34.50               | 237             | 1                                | 5                            |
| 35.00               | 246             | 1                                | 3                            |
| 35.50               | 256             | 1                                | 7                            |
| 36.00               | 265             | 1                                | 26                           |
| 36.50               | 275             | 1                                | 13                           |
| 37.00               | 284             | 1                                | 8                            |
| 37.50               | 294             | 1                                | 5                            |
| 38.00               | 303             | 1                                | 5                            |
| 38.50               | 312             | 1                                | 2                            |
| 39.00               | 322             | 1                                | 5                            |
| 39.50               | 331             | 1                                | 11                           |
| 40.00               | 341             | 1                                | 3                            |
| 40.50               | 350             | 1                                | 6                            |
| 41.00               | 360             | 1                                | 4                            |
| 41.50               | 369             | 1                                | 5                            |
| 42.00               | 378             | 1                                | 3                            |
| 42.50               | 388             | 1                                | 3                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 43.00               | 397             | 1                                | 6                            |
| 43.50               | 407             | 1                                | 7                            |
| 44.00               | 416             | 1                                | 2                            |
| 44.50               | 426             | 1                                | 2                            |
| 45.00               | 435             | 1                                | 6                            |
| 45.50               | 444             | 1                                | 19                           |
| 46.00               | 454             | 1                                | 60                           |
| 46.50               | 463             | 1                                | 30                           |
| 47.00               | 473             | 1                                | 18                           |
| 47.50               | 482             | 1                                | 5                            |
| 48.00               | 492             | 1                                | 9                            |
| 48.50               | 501             | 1                                | 3                            |
| 49.00               | 510             | 1                                | 22                           |
| 49.50               | 520             | 1                                | 12                           |
| 50.00               | 529             | 1                                | 14                           |
| 50.50               | 539             | 1                                | 17                           |
| 51.00               | 548             | 1                                | 17                           |
| 51.50               | 558             | 1                                | 7                            |
| 52.00               | 567             | 1                                | 7                            |
| 52.50               | 576             | 1                                | 11                           |
| 53.00               | 586             | 1                                | 9                            |
| 53.50               | 595             | 1                                | 19                           |
| 54.00               | 605             | 1                                | 13                           |
| 54.50               | 614             | 1                                | 9                            |
| 55.00               | 624             | 1                                | 15                           |
| 55.50               | 633             | 1                                | 6                            |
| 56.00               | 642             | 1                                | 5                            |
| 56.50               | 652             | 1                                | 8                            |
| 57.00               | 661             | 1                                | 30                           |
| 57.50               | 671             | 1                                | 18                           |
| 58.00               | 680             | 1                                | 14                           |
| 58.50               | 690             | 1                                | 14                           |
| 59.00               | 699             | 1                                | 15                           |
| 59.50               | 708             | 1                                | 7                            |
| 60.00               | 718             | 1                                | 16                           |
| 60.50               | 727             | 1                                | 85                           |
| 61.00               | 737             | 1                                | 10                           |
| 61.50               | 746             | 1                                | 5                            |
| 62.00               | 756             | 1                                | 9                            |
| 62.50               | 765             | 1                                | 8                            |
| 63.00               | 774             | 1                                | 6                            |
| 63.50               | 784             | 1                                | 8                            |
| 64.00               | 793             | 1                                | 10                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 64.50               | 803             | 1                                | 20                           |
| 65.00               | 812             | 1                                | 11                           |
| 65.50               | 822             | 1                                | 4                            |
| 66.00               | 831             | 1                                | 9                            |
| 66.50               | 840             | 1                                | 8                            |
| 67.00               | 850             | 1                                | 6                            |
| 67.50               | 859             | 1                                | 10                           |
| 68.00               | 869             | 1                                | 9                            |
| 68.50               | 878             | 1                                | 11                           |
| 69.00               | 888             | 1                                | 13                           |
| 69.50               | 897             | 1                                | 15                           |
| 70.00               | 906             | 1                                | 16                           |
| 70.50               | 916             | 1                                | 14                           |
| 71.00               | 925             | 1                                | 13                           |
| 71.50               | 935             | 1                                | 14                           |
| 72.00               | 944             | 1                                | 14                           |
| 72.50               | 954             | 1                                | 12                           |
| 73.00               | 963             | 1                                | 20                           |
| 73.50               | 972             | 1                                | 29                           |
| 74.00               | 982             | 1                                | 76                           |
| 74.50               | 991             | 1                                | 109                          |
| 75.00               | 1001            | 1                                | 54                           |
| 75.50               | 1010            | 1                                | 18                           |
| 76.00               | 1020            | 1                                | 15                           |
| 76.50               | 1029            | 1                                | 9                            |
| 77.00               | 1038            | 1                                | 11                           |
| 77.50               | 1048            | 1                                | 15                           |
| 78.00               | 1057            | 1                                | 16                           |
| 78.50               | 1067            | 1                                | 11                           |
| 79.00               | 1076            | 1                                | 19                           |
| 79.50               | 1086            | 1                                | 14                           |
| 80.00               | 1095            | 1                                | 4                            |
| 80.50               | 1104            | 1                                | 5                            |
| 81.00               | 1114            | 1                                | 7                            |
| 81.50               | 1123            | 1                                | 25                           |
| 82.00               | 1133            | 1                                | 19                           |
| 82.50               | 1142            | 1                                | 21                           |
| 83.00               | 1152            | 1                                | 4                            |
| 83.50               | 1161            | 1                                | 16                           |
| 84.00               | 1170            | 1                                | 29                           |

## Raw Charcoal data from Decker Lake

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 0.00                | -56             | 1                                | 4                            |
| 1.00                | -51             | 1                                | 5                            |
| 2.00                | -46             | 1                                | 17                           |
| 3.00                | -40             | 1                                | 9                            |
| 4.00                | -34             | 1                                | 5                            |
| 5.00                | -26             | 1                                | 6                            |
| 6.00                | -19             | 1                                | 2                            |
| 7.00                | -10             | 1                                | 0                            |
| 8.00                | -2              | 1                                | 12                           |
| 9.00                | 8               | 1                                | 5                            |
| 10.00               | 18              | 1                                | 3                            |
| 11.00               | 28              | 1                                | 2                            |
| 12.00               | 39              | 1                                | 7                            |
| 13.00               | 51              | 1                                | 3                            |
| 14.00               | 63              | 1                                | 0                            |
| 15.00               | 75              | 1                                | 7                            |
| 16.00               | 88              | 1                                | 10                           |
| 17.00               | 101             | 1                                | 9                            |
| 18.00               | 122             | 1                                | 4                            |
| 19.00               | 143             | 1                                | 7                            |
| 20.00               | 165             | 1                                | 8                            |
| 21.00               | 186             | 1                                | 11                           |
| 22.00               | 207             | 1                                | 12                           |
| 23.00               | 229             | 1                                | 8                            |
| 24.00               | 250             | 1                                | 7                            |
| 25.00               | 271             | 1                                | 5                            |
| 26.00               | 292             | 1                                | 17                           |
| 27.00               | 314             | 1                                | 6                            |
| 28.00               | 335             | 1                                | 5                            |
| 29.00               | 356             | 1                                | 6                            |
| 30.00               | 378             | 1                                | 5                            |
| 31.00               | 399             | 1                                | 4                            |
| 32.00               | 420             | 1                                | 3                            |
| 33.00               | 442             | 1                                | 9                            |
| 34.00               | 463             | 1                                | 18                           |
| 35.00               | 484             | 1                                | 17                           |
| 36.00               | 506             | 1                                | 16                           |
| 37.00               | 527             | 1                                | 3                            |
| 38.00               | 548             | 1                                | 2                            |
| 39.00               | 569             | 1                                | 30                           |
| 40.00               | 591             | 1                                | 16                           |
| 41.00               | 612             | 1                                | 27                           |
| 42.00               | 633             | 1                                | 25                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 43.00               | 655             | 1                                | 24                           |
| 44.00               | 676             | 1                                | 16                           |
| 45.00               | 697             | 1                                | 10                           |
| 46.00               | 719             | 1                                | 9                            |
| 47.00               | 740             | 1                                | 6                            |
| 48.00               | 761             | 1                                | 9                            |
| 49.00               | 783             | 1                                | 14                           |
| 50.00               | 804             | 1                                | 4                            |
| 51.00               | 825             | 1                                | 11                           |
| 52.00               | 846             | 1                                | 11                           |
| 53.00               | 868             | 1                                | 15                           |
| 54.00               | 889             | 1                                | 6                            |
| 55.00               | 910             | 1                                | 6                            |
| 56.00               | 932             | 1                                | 8                            |
| 57.00               | 953             | 1                                | 9                            |
| 58.00               | 974             | 1                                | 8                            |
| 59.00               | 996             | 1                                | 23                           |
| 60.00               | 1017            | 1                                | 6                            |
| 61.00               | 1038            | 1                                | 32                           |
| 62.00               | 1060            | 1                                | 12                           |
| 63.00               | 1081            | 1                                | 6                            |
| 64.00               | 1102            | 1                                | 10                           |
| 65.00               | 1123            | 1                                | 22                           |
| 66.00               | 1145            | 1                                | 11                           |
| 67.00               | 1166            | 1                                | 16                           |
| 68.00               | 1187            | 1                                | 14                           |
| 69.00               | 1209            | 1                                | 1                            |
| 70.00               | 1230            | 1                                | 13                           |
| 71.00               | 1251            | 1                                | 10                           |
| 72.00               | 1273            | 1                                | 19                           |
| 73.00               | 1294            | 1                                | 22                           |
| 74.00               | 1315            | 1                                | 9                            |
| 75.00               | 1337            | 1                                | 8                            |
| 76.00               | 1358            | 1                                | 26                           |
| 77.00               | 1379            | 1                                | 10                           |
| 78.00               | 1400            | 1                                | 13                           |
| 79.00               | 1422            | 1                                | 15                           |
| 80.00               | 1443            | 1                                | 17                           |
| 81.00               | 1464            | 1                                | 24                           |
| 82.00               | 1486            | 1                                | 18                           |
| 83.00               | 1507            | 1                                | 29                           |
| 84.00               | 1528            | 1                                | 18                           |
| 85.00               | 1550            | 1                                | 24                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 86.00               | 1571            | 1                                | 24                           |
| 87.00               | 1592            | 1                                | 12                           |
| 88.00               | 1614            | 1                                | 13                           |
| 89.00               | 1635            | 1                                | 30                           |
| 90.00               | 1656            | 1                                | 18                           |
| 91.00               | 1677            | 1                                | 9                            |
| 92.00               | 1699            | 1                                | 23                           |
| 93.00               | 1720            | 1                                | 9                            |
| 94.00               | 1741            | 1                                | 20                           |
| 95.00               | 1763            | 1                                | 17                           |
| 96.00               | 1784            | 1                                | 7                            |
| 97.00               | 1805            | 1                                | 12                           |
| 98.00               | 1827            | 1                                | 26                           |
| 99.00               | 1848            | 1                                | 30                           |
| 100.00              | 1869            | 1                                | 14                           |

## Raw Charcoal data from Reservoir Lake

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 29                  | -25             | 2                                | 0                            |
| 30                  | -23             | 2                                | 1                            |
| 31                  | -21             | 2                                | 0                            |
| 32                  | -18             | 2                                | 0                            |
| 33                  | -16             | 2                                | 0                            |
| 34                  | -13             | 2                                | 0                            |
| 35                  | -10             | 2                                | 0                            |
| 36                  | -8              | 2                                | 3                            |
| 37                  | -5              | 2                                | 2                            |
| 38                  | -2              | 2                                | 3                            |
| 39                  | 1               | 2                                | 6                            |
| 40                  | 4               | 2                                | 1                            |
| 41                  | 7               | 2                                | 2                            |
| 42                  | 10              | 2                                | 4                            |
| 43                  | 13              | 2                                | 0                            |
| 44                  | 17              | 2                                | 2                            |
| 45                  | 20              | 2                                | 0                            |
| 46                  | 23              | 2                                | 0                            |
| 47                  | 27              | 2                                | 2                            |
| 48                  | 30              | 2                                | 5                            |
| 49                  | 33              | 2                                | 6                            |
| 50                  | 37              | 2                                | 3                            |
| 51                  | 40              | 2                                | 5                            |
| 52                  | 54              | 2                                | 3                            |
| 53                  | 68              | 2                                | 10                           |
| 54                  | 82              | 2                                | 15                           |
| 55                  | 96              | 2                                | 4                            |
| 56                  | 110             | 2                                | 16                           |
| 57                  | 124             | 2                                | 11                           |
| 58                  | 138             | 2                                | 10                           |
| 59                  | 152             | 2                                | 14                           |
| 60                  | 166             | 2                                | 12                           |
| 61                  | 180             | 2                                | 7                            |
| 62                  | 194             | 2                                | 11                           |
| 63                  | 208             | 2                                | 4                            |
| 64                  | 221             | 2                                | 0                            |
| 65                  | 235             | 2                                | 6                            |
| 66                  | 249             | 2                                | 11                           |
| 67                  | 263             | 2                                | 5                            |
| 68                  | 276             | 2                                | 15                           |
| 69                  | 290             | 2                                | 16                           |
| 70                  | 303             | 2                                | 12                           |
| 71                  | 317             | 2                                | 6                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 72                  | 330             | 2                                | 21                           |
| 73                  | 344             | 2                                | 13                           |
| 74                  | 357             | 2                                | 0                            |
| 75                  | 370             | 2                                | 10                           |
| 76                  | 384             | 2                                | 0                            |
| 77                  | 397             | 2                                | 9                            |
| 78                  | 410             | 2                                | 10                           |
| 79                  | 423             | 2                                | 16                           |
| 80                  | 436             | 2                                | 11                           |
| 81                  | 449             | 2                                | 1                            |
| 82                  | 462             | 2                                | 11                           |
| 83                  | 474             | 2                                | 5                            |
| 84                  | 487             | 2                                | 10                           |
| 85                  | 499             | 2                                | 5                            |
| 86                  | 512             | 2                                | 6                            |
| 87                  | 524             | 2                                | 3                            |
| 88                  | 536             | 2                                | 6                            |
| 89                  | 549             | 2                                | 7                            |
| 90                  | 561             | 2                                | 10                           |
| 91                  | 573             | 2                                | 9                            |
| 92                  | 584             | 2                                | 14                           |
| 93                  | 596             | 2                                | 20                           |
| 94                  | 608             | 2                                | 20                           |
| 95                  | 619             | 2                                | 31                           |
| 96                  | 631             | 2                                | 14                           |
| 97                  | 642             | 2                                | 14                           |
| 98                  | 653             | 2                                | 16                           |
| 99                  | 664             | 2                                | 45                           |
| 100                 | 675             | 2                                | 9                            |
| 101                 | 686             | 2                                | 0                            |
| 102                 | 696             | 2                                | 2                            |
| 103                 | 707             | 2                                | 3                            |
| 104                 | 717             | 2                                | 2                            |
| 105                 | 728             | 2                                | 11                           |
| 106                 | 738             | 2                                | 10                           |
| 107                 | 748             | 2                                | 7                            |
| 108                 | 757             | 2                                | 15                           |
| 109                 | 767             | 2                                | 45                           |
| 110                 | 777             | 2                                | 5                            |
| 111                 | 786             | 2                                | 2                            |
| 112                 | 795             | 2                                | 6                            |
| 113                 | 804             | 2                                | 2                            |
| 114                 | 813             | 2                                | 5                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 115                 | 822             | 2                                | 22                           |
| 116                 | 831             | 2                                | 19                           |
| 117                 | 840             | 2                                | 13                           |
| 118                 | 848             | 2                                | 12                           |
| 119                 | 856             | -999                             | -999                         |
| 120                 | 865             | 2                                | 5                            |
| 121                 | 873             | 2                                | 10                           |
| 122                 | 881             | 2                                | 3                            |
| 123                 | 889             | 2                                | 4                            |
| 124                 | 896             | 2                                | 20                           |
| 125                 | 904             | 2                                | 27                           |
| 126                 | 912             | 2                                | 24                           |
| 127                 | 919             | 2                                | 22                           |
| 128                 | 926             | 2                                | 15                           |
| 129                 | 934             | 2                                | 3                            |
| 130                 | 941             | 2                                | 9                            |
| 131                 | 948             | 2                                | 5                            |
| 132                 | 955             | 2                                | 4                            |
| 133                 | 962             | 2                                | 9                            |
| 134                 | 968             | 2                                | 2                            |
| 135                 | 975             | 2                                | 7                            |
| 136                 | 982             | 2                                | 26                           |
| 137                 | 988             | 2                                | 12                           |
| 138                 | 995             | 2                                | 3                            |
| 139                 | 1001            | 2                                | 9                            |
| 140                 | 1007            | 2                                | 9                            |
| 141                 | 1013            | 2                                | 9                            |
| 142                 | 1019            | 2                                | 29                           |
| 143                 | 1025            | 2                                | 30                           |
| 144                 | 1031            | 2                                | 37                           |
| 145                 | 1037            | 2                                | 31                           |
| 146                 | 1043            | 2                                | 21                           |
| 147                 | 1048            | 2                                | 38                           |
| 148                 | 1054            | 2                                | 24                           |
| 149                 | 1060            | 2                                | 10                           |
| 150                 | 1065            | 2                                | 20                           |
| 151                 | 1071            | 2                                | 16                           |
| 152                 | 1076            | 2                                | 9                            |
| 153                 | 1081            | 2                                | 8                            |
| 154                 | 1086            | 2                                | 3                            |
| 155                 | 1092            | 2                                | 2                            |
| 156                 | 1097            | 2                                | 9                            |
| 157                 | 1102            | 2                                | 4                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 158                 | 1107            | 2                                | 15                           |
| 159                 | 1112            | 2                                | 22                           |
| 160                 | 1117            | 2                                | 23                           |
| 161                 | 1122            | 2                                | 20                           |
| 162                 | 1127            | 2                                | 8                            |
| 163                 | 1131            | 2                                | 17                           |
| 164                 | 1136            | 2                                | 26                           |
| 165                 | 1141            | 2                                | 16                           |
| 166                 | 1146            | 2                                | 3                            |
| 167                 | 1150            | 2                                | 13                           |
| 168                 | 1155            | 2                                | 8                            |
| 169                 | 1159            | 2                                | 42                           |
| 170                 | 1164            | 2                                | 17                           |
| 171                 | 1169            | 2                                | 12                           |
| 172                 | 1173            | 2                                | 31                           |
| 173                 | 1178            | 2                                | 28                           |
| 174                 | 1182            | 2                                | 5                            |
| 175                 | 1187            | 2                                | 3                            |
| 176                 | 1191            | 2                                | 4                            |
| 177                 | 1195            | 2                                | 23                           |
| 178                 | 1200            | 2                                | 7                            |
| 179                 | 1204            | 2                                | 31                           |
| 180                 | 1209            | 2                                | 17                           |
| 181                 | 1213            | 2                                | 20                           |
| 182                 | 1217            | 2                                | 15                           |
| 183                 | 1222            | 2                                | 5                            |
| 184                 | 1226            | 2                                | 9                            |
| 185                 | 1230            | 2                                | 19                           |
| 186                 | 1235            | 2                                | 3                            |
| 187                 | 1239            | 2                                | 6                            |
| 188                 | 1243            | 2                                | 41                           |
| 189                 | 1248            | 2                                | 6                            |
| 190                 | 1252            | 2                                | 36                           |
| 191                 | 1257            | 2                                | 21                           |
| 192                 | 1261            | 2                                | 14                           |
| 193                 | 1265            | 2                                | 4                            |
| 194                 | 1270            | 2                                | 15                           |
| 195                 | 1274            | 2                                | 10                           |
| 196                 | 1279            | 2                                | 9                            |
| 197                 | 1283            | 2                                | 10                           |
| 198                 | 1288            | 2                                | 13                           |
| 199                 | 1292            | 2                                | 24                           |
| 200                 | 1297            | 2                                | 38                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 201                 | 1301            | 2                                | 14                           |
| 202                 | 1306            | 2                                | 8                            |
| 203                 | 1311            | 2                                | 24                           |
| 204                 | 1315            | 2                                | 9                            |
| 205                 | 1320            | 2                                | 9                            |
| 206                 | 1325            | 2                                | 33                           |
| 207                 | 1330            | 2                                | 17                           |
| 208                 | 1334            | 2                                | 8                            |
| 209                 | 1339            | 2                                | 7                            |
| 210                 | 1344            | 2                                | 20                           |
| 211                 | 1349            | 2                                | 15                           |
| 212                 | 1354            | 2                                | 14                           |
| 213                 | 1359            | 2                                | 25                           |
| 214                 | 1364            | 2                                | 25                           |
| 215                 | 1369            | 2                                | 47                           |
| 216                 | 1375            | 2                                | 25                           |
| 217                 | 1380            | 2                                | 24                           |
| 218                 | 1385            | -999                             | -999                         |
| 219                 | 1391            | 2                                | 31                           |
| 220                 | 1396            | 2                                | 33                           |
| 221                 | 1402            | 2                                | 23                           |
| 222                 | 1407            | 2                                | 12                           |
| 223                 | 1413            | 2                                | 7                            |
| 224                 | 1419            | 2                                | 4                            |
| 225                 | 1424            | 2                                | 24                           |
| 226                 | 1430            | 2                                | 12                           |
| 227                 | 1436            | 2                                | 11                           |
| 228                 | 1442            | 2                                | 4                            |
| 229                 | 1448            | 2                                | 49                           |
| 230                 | 1454            | -999                             | -999                         |
| 231                 | 1461            | 2                                | 14                           |
| 232                 | 1467            | 2                                | 28                           |
| 233                 | 1473            | 2                                | 13                           |
| 234                 | 1480            | 2                                | 17                           |
| 235                 | 1486            | 2                                | 18                           |
| 236                 | 1493            | 2                                | 9                            |
| 237                 | 1500            | 2                                | 28                           |
| 238                 | 1506            | 2                                | 17                           |
| 239                 | 1513            | 2                                | 28                           |
| 240                 | 1520            | 2                                | 36                           |
| 241                 | 1527            | 2                                | 10                           |
| 242                 | 1534            | 2                                | 7                            |
| 243                 | 1541            | 2                                | 19                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 244                 | 1548            | 2                                | 33                           |
| 245                 | 1555            | 2                                | 7                            |
| 246                 | 1563            | 2                                | 11                           |
| 247                 | 1570            | 2                                | 7                            |
| 248                 | 1577            | 2                                | 9                            |
| 249                 | 1585            | 2                                | 14                           |
| 250                 | 1592            | 2                                | 20                           |
| 251                 | 1600            | 2                                | 32                           |
| 252                 | 1607            | 2                                | 29                           |
| 253                 | 1615            | 2                                | 35                           |
| 254                 | 1623            | 2                                | 39                           |
| 255                 | 1630            | 2                                | 17                           |
| 256                 | 1638            | 2                                | 8                            |
| 257                 | 1646            | 2                                | 73                           |
| 258                 | 1654            | 2                                | 46                           |
| 259                 | 1662            | 2                                | 43                           |
| 260                 | 1670            | 2                                | 55                           |
| 261                 | 1678            | 2                                | 62                           |
| 262                 | 1686            | 2                                | 26                           |
| 263                 | 1694            | 2                                | 10                           |
| 264                 | 1703            | 2                                | 17                           |
| 265                 | 1711            | 2                                | 48                           |
| 266                 | 1719            | 2                                | 52                           |
| 267                 | 1728            | 2                                | 38                           |
| 268                 | 1736            | 2                                | 20                           |
| 269                 | 1745            | 2                                | 20                           |
| 270                 | 1753            | 2                                | 8                            |
| 271                 | 1762            | 2                                | 25                           |
| 272                 | 1770            | 2                                | 19                           |
| 273                 | 1779            | 2                                | 11                           |
| 274                 | 1787            | 2                                | 25                           |
| 275                 | 1796            | 2                                | 23                           |
| 276                 | 1805            | 2                                | 56                           |
| 277                 | 1814            | 2                                | 17                           |
| 278                 | 1822            | 2                                | 15                           |
| 279                 | 1831            | 2                                | 3                            |
| 280                 | 1840            | 2                                | 3                            |
| 281                 | 1849            | 2                                | 19                           |
| 282                 | 1858            | 2                                | 11                           |
| 283                 | 1867            | 2                                | 9                            |
| 284                 | 1876            | 2                                | 20                           |
| 285                 | 1885            | 2                                | 10                           |
| 286                 | 1894            | 2                                | 9                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 287                 | 1903            | 2                                | 19                           |
| 288                 | 1912            | 2                                | 32                           |
| 289                 | 1922            | 2                                | 25                           |
| 290                 | 1931            | 2                                | 11                           |
| 291                 | 1940            | 2                                | 27                           |
| 292                 | 1949            | 2                                | 39                           |
| 293                 | 1959            | 2                                | 11                           |
| 294                 | 1968            | 2                                | 3                            |
| 295                 | 1977            | 2                                | 2                            |
| 296                 | 1987            | 2                                | 60                           |
| 297                 | 1996            | 2                                | 3                            |
| 298                 | 2005            | 2                                | 4                            |
| 299                 | 2015            | 2                                | 2                            |
| 300                 | 2024            | 2                                | 17                           |
| 301                 | 2034            | 2                                | 0                            |
| 302                 | 2043            | 2                                | 12                           |
| 303                 | 2053            | 2                                | 11                           |
| 304                 | 2062            | 2                                | 23                           |
| 305                 | 2072            | 2                                | 4                            |
| 306                 | 2081            | 2                                | 17                           |
| 307                 | 2091            | 2                                | 4                            |
| 308                 | 2101            | 2                                | 2                            |
| 309                 | 2110            | 2                                | 14                           |
| 310                 | 2120            | 2                                | 6                            |
| 311                 | 2129            | 2                                | 9                            |
| 312                 | 2139            | 2                                | 27                           |
| 313                 | 2149            | 2                                | 6                            |
| 314                 | 2158            | 2                                | 6                            |
| 315                 | 2168            | 2                                | 40                           |
| 316                 | 2178            | 2                                | 15                           |
| 317                 | 2188            | 2                                | 12                           |
| 318                 | 2197            | 2                                | 9                            |
| 319                 | 2207            | 2                                | 3                            |
| 320                 | 2217            | 2                                | 7                            |
| 321                 | 2227            | 2                                | 11                           |
| 322                 | 2237            | 2                                | 10                           |
| 323                 | 2246            | 2                                | 21                           |
| 324                 | 2256            | 2                                | 23                           |
| 325                 | 2266            | 2                                | 25                           |
| 326                 | 2276            | 2                                | 4                            |
| 327                 | 2286            | 2                                | 2                            |
| 328                 | 2296            | 2                                | 12                           |
| 329                 | 2306            | 2                                | 6                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 330                 | 2316            | 2                                | 27                           |
| 331                 | 2326            | 2                                | 8                            |
| 332                 | 2336            | 2                                | 8                            |
| 333                 | 2346            | 2                                | 4                            |
| 334                 | 2356            | 2                                | 0                            |
| 335                 | 2366            | 2                                | 5                            |
| 336                 | 2376            | 2                                | 18                           |
| 337                 | 2386            | 2                                | 14                           |
| 338                 | 2396            | 2                                | 13                           |
| 339                 | 2406            | 2                                | 6                            |
| 340                 | 2416            | 2                                | 40                           |
| 341                 | 2426            | 2                                | 14                           |
| 342                 | 2436            | 2                                | 12                           |
| 343                 | 2446            | 2                                | 13                           |
| 344                 | 2456            | 2                                | 6                            |
| 345                 | 2466            | 2                                | 10                           |
| 346                 | 2476            | 2                                | 14                           |
| 347                 | 2486            | 2                                | 19                           |
| 348                 | 2496            | 2                                | 30                           |
| 349                 | 2507            | 2                                | 43                           |
| 350                 | 2517            | 2                                | 24                           |
| 351                 | 2527            | 2                                | 25                           |
| 352                 | 2537            | 2                                | 107                          |
| 353                 | 2547            | 2                                | 33                           |
| 354                 | 2557            | 2                                | 15                           |
| 355                 | 2567            | 2                                | 16                           |
| 356                 | 2578            | 2                                | 40                           |
| 357                 | 2588            | 2                                | 22                           |
| 358                 | 2598            | 2                                | 64                           |
| 359                 | 2608            | 2                                | 32                           |
| 360                 | 2618            | 2                                | 13                           |
| 361                 | 2629            | 2                                | 15                           |
| 362                 | 2639            | 2                                | 17                           |
| 363                 | 2649            | 2                                | 9                            |
| 364                 | 2659            | 2                                | 14                           |
| 365                 | 2669            | 2                                | 16                           |
| 366                 | 2680            | 2                                | 57                           |
| 367                 | 2690            | 2                                | 23                           |
| 368                 | 2700            | 2                                | 39                           |
| 369                 | 2710            | 2                                | 16                           |
| 370                 | 2721            | 2                                | 21                           |
| 371                 | 2731            | 2                                | 21                           |
| 372                 | 2741            | 2                                | 4                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 373                 | 2752            | 2                                | 0                            |
| 374                 | 2762            | 2                                | 48                           |
| 375                 | 2772            | 2                                | 38                           |
| 376                 | 2783            | 2                                | 46                           |
| 377                 | 2793            | 2                                | 57                           |
| 378                 | 2803            | 2                                | 19                           |
| 379                 | 2814            | 2                                | 33                           |
| 380                 | 2824            | 2                                | 91                           |
| 381                 | 2834            | 2                                | 38                           |
| 382                 | 2845            | 2                                | 9                            |
| 383                 | 2855            | 2                                | 10                           |
| 384                 | 2865            | 2                                | 28                           |
| 385                 | 2876            | 2                                | 15                           |
| 386                 | 2886            | 2                                | 10                           |
| 387                 | 2896            | 2                                | 7                            |
| 388                 | 2907            | 2                                | 5                            |
| 389                 | 2917            | 2                                | 33                           |
| 390                 | 2928            | 2                                | 19                           |
| 391                 | 2938            | 2                                | 18                           |
| 392                 | 2949            | 2                                | 9                            |
| 393                 | 2959            | 2                                | 23                           |
| 394                 | 2970            | 2                                | 12                           |
| 395                 | 2980            | 2                                | 15                           |
| 396                 | 2990            | 2                                | 16                           |
| 397                 | 3001            | 2                                | 29                           |
| 398                 | 3011            | 2                                | 29                           |
| 399                 | 3022            | 2                                | 17                           |
| 400                 | 3032            | 2                                | 0                            |
| 401                 | 3043            | 2                                | 24                           |
| 402                 | 3054            | 2                                | 15                           |
| 403                 | 3064            | 2                                | 9                            |
| 404                 | 3075            | 2                                | 29                           |
| 405                 | 3085            | 2                                | 23                           |
| 406                 | 3096            | 2                                | 39                           |
| 407                 | 3106            | 2                                | 11                           |
| 408                 | 3117            | 2                                | 9                            |
| 409                 | 3128            | 2                                | 6                            |
| 410                 | 3138            | 2                                | 8                            |
| 411                 | 3149            | 2                                | 16                           |
| 412                 | 3159            | 2                                | 6                            |
| 413                 | 3170            | 2                                | 57                           |
| 414                 | 3181            | 2                                | 22                           |
| 415                 | 3191            | 2                                | 17                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 416                 | 3202            | 2                                | 12                           |
| 417                 | 3213            | 2                                | 22                           |
| 418                 | 3224            | 2                                | 7                            |
| 419                 | 3234            | 2                                | 17                           |
| 420                 | 3245            | 2                                | 16                           |
| 421                 | 3256            | 2                                | 19                           |
| 422                 | 3267            | 2                                | 71                           |
| 423                 | 3277            | 2                                | 10                           |
| 424                 | 3288            | 2                                | 0                            |
| 425                 | 3299            | 2                                | 17                           |
| 426                 | 3310            | 2                                | 8                            |
| 427                 | 3320            | 2                                | 114                          |
| 428                 | 3331            | 2                                | 15                           |
| 429                 | 3342            | 2                                | 12                           |
| 430                 | 3353            | 2                                | 48                           |
| 431                 | 3364            | 2                                | 28                           |
| 432                 | 3375            | 2                                | 16                           |
| 433                 | 3386            | 2                                | 24                           |
| 434                 | 3397            | 2                                | 12                           |
| 435                 | 3407            | 2                                | 53                           |
| 436                 | 3418            | 2                                | 23                           |
| 437                 | 3429            | 2                                | 63                           |
| 438                 | 3440            | 2                                | 18                           |
| 439                 | 3451            | 2                                | 38                           |
| 440                 | 3462            | 2                                | 17                           |
| 441                 | 3473            | 2                                | 17                           |
| 442                 | 3484            | 2                                | 20                           |
| 443                 | 3495            | 2                                | 22                           |
| 444                 | 3506            | 2                                | 18                           |
| 445                 | 3517            | 2                                | 0                            |
| 446                 | 3528            | 2                                | 8                            |
| 447                 | 3539            | 2                                | 30                           |
| 448                 | 3551            | 2                                | 40                           |
| 449                 | 3562            | 2                                | 22                           |
| 450                 | 3573            | 2                                | 19                           |
| 451                 | 3584            | 2                                | 2                            |
| 452                 | 3595            | 2                                | 15                           |
| 453                 | 3606            | 2                                | 6                            |
| 454                 | 3617            | 2                                | 11                           |
| 455                 | 3629            | 2                                | 55                           |
| 456                 | 3640            | 2                                | 12                           |
| 457                 | 3651            | 2                                | 149                          |
| 458                 | 3662            | 2                                | 15                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 459                 | 3673            | 2                                | 22                           |
| 460                 | 3685            | 2                                | 27                           |
| 461                 | 3696            | 2                                | 11                           |
| 462                 | 3707            | 2                                | 6                            |
| 463                 | 3719            | 2                                | 26                           |
| 464                 | 3730            | 2                                | 3                            |
| 465                 | 3741            | 2                                | 39                           |
| 466                 | 3753            | 2                                | 20                           |
| 467                 | 3764            | 2                                | 17                           |
| 468                 | 3775            | 2                                | 19                           |
| 469                 | 3787            | 2                                | 51                           |
| 470                 | 3798            | 2                                | 25                           |
| 471                 | 3810            | 2                                | 16                           |
| 472                 | 3821            | 2                                | 12                           |
| 473                 | 3833            | 2                                | 4                            |
| 474                 | 3844            | 2                                | 36                           |
| 475                 | 3856            | 2                                | 11                           |
| 476                 | 3867            | 2                                | 7                            |
| 477                 | 3879            | 2                                | 21                           |
| 478                 | 3890            | 2                                | 15                           |
| 479                 | 3902            | 2                                | 7                            |
| 480                 | 3913            | 2                                | 18                           |
| 481                 | 3925            | 2                                | 13                           |
| 482                 | 3937            | 2                                | 3                            |
| 483                 | 3948            | 2                                | 2                            |
| 484                 | 3960            | 2                                | 2                            |
| 485                 | 3972            | 2                                | 6                            |
| 486                 | 3983            | 2                                | 26                           |
| 487                 | 3995            | 2                                | 22                           |
| 488                 | 4007            | 2                                | 15                           |
| 489                 | 4019            | 2                                | 11                           |
| 490                 | 4030            | 2                                | 72                           |
| 491                 | 4042            | 2                                | 35                           |
| 492                 | 4054            | 2                                | 14                           |
| 493                 | 4066            | 2                                | 16                           |
| 494                 | 4078            | 2                                | 55                           |
| 495                 | 4089            | 2                                | 13                           |
| 496                 | 4101            | 2                                | 22                           |
| 497                 | 4113            | 2                                | 25                           |
| 498                 | 4125            | 2                                | 5                            |
| 499                 | 4137            | 2                                | 19                           |
| 500                 | 4149            | 2                                | 31                           |
| 501                 | 4161            | 2                                | 19                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 502                 | 4173            | 2                                | 17                           |
| 503                 | 4185            | 2                                | 39                           |
| 504                 | 4197            | 2                                | 17                           |
| 505                 | 4209            | 2                                | 16                           |
| 506                 | 4221            | 2                                | 26                           |
| 507                 | 4233            | 2                                | 41                           |
| 508                 | 4245            | 2                                | 14                           |
| 509                 | 4257            | 2                                | 26                           |
| 510                 | 4269            | 2                                | 6                            |
| 511                 | 4282            | 2                                | 8                            |
| 512                 | 4294            | 2                                | 21                           |
| 513                 | 4306            | 2                                | 18                           |
| 514                 | 4318            | 2                                | 28                           |
| 515                 | 4331            | 2                                | 56                           |
| 516                 | 4343            | 2                                | 26                           |
| 517                 | 4355            | 2                                | 26                           |
| 518                 | 4367            | 2                                | 31                           |
| 519                 | 4380            | 2                                | 25                           |
| 520                 | 4392            | 2                                | 27                           |
| 521                 | 4404            | 2                                | 45                           |
| 522                 | 4417            | 2                                | 27                           |
| 523                 | 4429            | 2                                | 34                           |
| 524                 | 4442            | 2                                | 78                           |
| 525                 | 4454            | 2                                | 17                           |
| 526                 | 4467            | 2                                | 12                           |
| 527                 | 4479            | 2                                | 13                           |
| 528                 | 4492            | 2                                | 43                           |
| 529                 | 4504            | 2                                | 12                           |
| 530                 | 4517            | 2                                | 19                           |
| 531                 | 4529            | 2                                | 33                           |
| 532                 | 4542            | 2                                | 8                            |
| 533                 | 4554            | 2                                | 24                           |
| 534                 | 4567            | 2                                | 52                           |
| 535                 | 4580            | 2                                | 28                           |
| 536                 | 4592            | 2                                | 8                            |
| 537                 | 4605            | 2                                | 21                           |
| 538                 | 4618            | 2                                | 36                           |
| 539                 | 4631            | 2                                | 18                           |
| 540                 | 4643            | 2                                | 32                           |
| 541                 | 4656            | 2                                | 0                            |
| 542                 | 4669            | 2                                | 71                           |
| 543                 | 4682            | 2                                | 28                           |
| 544                 | 4695            | 2                                | 17                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 545                 | 4708            | 2                                | 15                           |
| 546                 | 4721            | 2                                | 15                           |
| 547                 | 4734            | 2                                | 16                           |
| 548                 | 4746            | 2                                | 20                           |
| 549                 | 4759            | 2                                | 6                            |
| 550                 | 4772            | 2                                | 32                           |
| 551                 | 4786            | 2                                | 5                            |
| 552                 | 4799            | 2                                | 22                           |
| 553                 | 4812            | 2                                | 28                           |
| 554                 | 4825            | 2                                | 12                           |
| 555                 | 4838            | 2                                | 16                           |
| 556                 | 4851            | 2                                | 23                           |
| 557                 | 4864            | 2                                | 45                           |
| 558                 | 4877            | 2                                | 13                           |
| 559                 | 4891            | 2                                | 13                           |
| 560                 | 4904            | 2                                | 15                           |
| 561                 | 4917            | 2                                | 17                           |
| 562                 | 4930            | 2                                | 19                           |
| 563                 | 4944            | 2                                | 21                           |
| 564                 | 4957            | 2                                | 43                           |
| 565                 | 4971            | 2                                | 3                            |
| 566                 | 4984            | 2                                | 5                            |
| 567                 | 4997            | 2                                | 28                           |
| 568                 | 5011            | 2                                | 144                          |
| 569                 | 5024            | 2                                | 27                           |
| 570                 | 5038            | 2                                | 13                           |
| 571                 | 5051            | 2                                | 18                           |
| 572                 | 5065            | 2                                | 13                           |
| 573                 | 5078            | 2                                | 68                           |
| 574                 | 5092            | 2                                | 47                           |
| 575                 | 5106            | 2                                | 29                           |
| 576                 | 5119            | 2                                | 11                           |
| 577                 | 5133            | 2                                | 13                           |
| 578                 | 5147            | 2                                | 57                           |
| 579                 | 5160            | 2                                | 34                           |
| 580                 | 5174            | 2                                | 82                           |
| 581                 | 5188            | 2                                | 40                           |
| 582                 | 5202            | 2                                | 21                           |
| 583                 | 5216            | 2                                | 31                           |
| 584                 | 5229            | 2                                | 41                           |
| 585                 | 5243            | 2                                | 52                           |
| 586                 | 5257            | 2                                | 22                           |
| 587                 | 5271            | 2                                | 38                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 588                 | 5285            | 2                                | 43                           |
| 589                 | 5299            | 2                                | 30                           |
| 590                 | 5313            | 2                                | 32                           |
| 591                 | 5327            | 2                                | 54                           |
| 592                 | 5341            | 2                                | 36                           |
| 593                 | 5355            | 2                                | 28                           |
| 594                 | 5370            | 2                                | 13                           |
| 595                 | 5384            | 2                                | 36                           |
| 596                 | 5398            | 2                                | 18                           |
| 597                 | 5412            | 2                                | 21                           |
| 598                 | 5426            | 2                                | 20                           |
| 599                 | 5441            | 2                                | 52                           |
| 600                 | 5455            | 2                                | 37                           |
| 601                 | 5469            | 2                                | 49                           |
| 602                 | 5484            | 2                                | 59                           |
| 603                 | 5498            | 2                                | 39                           |
| 604                 | 5512            | 2                                | 22                           |
| 605                 | 5527            | 2                                | 26                           |
| 606                 | 5541            | 2                                | 10                           |
| 607                 | 5556            | 2                                | 20                           |
| 608                 | 5570            | 2                                | 33                           |
| 609                 | 5585            | 2                                | 22                           |
| 610                 | 5599            | 2                                | 37                           |
| 611                 | 5614            | 2                                | 32                           |
| 612                 | 5629            | 2                                | 25                           |
| 613                 | 5643            | 2                                | 16                           |
| 614                 | 5658            | 2                                | 15                           |
| 615                 | 5673            | 2                                | 17                           |
| 616                 | 5688            | 2                                | 0                            |
| 617                 | 5702            | 2                                | 2                            |
| 618                 | 5717            | 2                                | 7                            |
| 619                 | 5732            | 2                                | 7                            |
| 620                 | 5747            | 2                                | 8                            |
| 621                 | 5762            | 2                                | 5                            |
| 622                 | 5777            | 2                                | 21                           |
| 623                 | 5792            | 2                                | 4                            |
| 624                 | 5807            | 2                                | 40                           |
| 625                 | 5822            | 2                                | 2                            |
| 626                 | 5837            | 2                                | 11                           |
| 627                 | 5852            | 2                                | 12                           |
| 628                 | 5867            | 2                                | 9                            |
| 629                 | 5882            | 2                                | 5                            |
| 630                 | 5897            | 2                                | 22                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 631                 | 5913            | 2                                | 25                           |
| 632                 | 5928            | 2                                | 59                           |
| 633                 | 5943            | 2                                | 13                           |
| 634                 | 5958            | 2                                | 28                           |
| 635                 | 5974            | 2                                | 13                           |
| 636                 | 5989            | 2                                | 30                           |
| 637                 | 6005            | 2                                | 42                           |
| 638                 | 6020            | 2                                | 34                           |
| 639                 | 6035            | 2                                | 16                           |
| 640                 | 6051            | 2                                | 14                           |
| 641                 | 6067            | 2                                | 19                           |
| 642                 | 6082            | 2                                | 27                           |
| 643                 | 6098            | 2                                | 38                           |
| 644                 | 6113            | 2                                | 22                           |
| 645                 | 6129            | 2                                | 21                           |
| 646                 | 6145            | 2                                | 14                           |
| 647                 | 6160            | 2                                | 42                           |
| 648                 | 6176            | 2                                | 30                           |
| 649                 | 6192            | 2                                | 37                           |
| 650                 | 6208            | 2                                | 34                           |
| 651                 | 6224            | 2                                | 35                           |
| 652                 | 6239            | 2                                | 36                           |
| 653                 | 6255            | 2                                | 29                           |
| 654                 | 6271            | 2                                | 44                           |
| 655                 | 6287            | 2                                | 35                           |
| 656                 | 6303            | 2                                | 54                           |
| 657                 | 6319            | 2                                | 64                           |
| 658                 | 6335            | 2                                | 50                           |
| 659                 | 6352            | 2                                | 48                           |
| 660                 | 6368            | 2                                | 38                           |
| 661                 | 6384            | 2                                | 22                           |
| 662                 | 6400            | 2                                | 23                           |
| 663                 | 6416            | 2                                | 17                           |
| 664                 | 6433            | 2                                | 13                           |
| 665                 | 6449            | 2                                | 22                           |
| 666                 | 6465            | 2                                | 33                           |
| 667                 | 6482            | 2                                | 34                           |
| 668                 | 6498            | 2                                | 37                           |
| 669                 | 6515            | 2                                | 29                           |
| 670                 | 6531            | 2                                | 40                           |
| 671                 | 6548            | 2                                | 60                           |
| 672                 | 6564            | 2                                | 86                           |
| 673                 | 6581            | 2                                | 37                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 674                 | 6597            | 2                                | 47                           |
| 675                 | 6614            | 2                                | 40                           |
| 676                 | 6631            | 2                                | 60                           |
| 677                 | 6648            | 2                                | 45                           |
| 678                 | 6664            | 2                                | 42                           |
| 679                 | 6681            | 2                                | 37                           |
| 680                 | 6698            | 2                                | 66                           |
| 681                 | 6715            | 2                                | 100                          |
| 682                 | 6732            | 2                                | 65                           |
| 683                 | 6749            | 2                                | 102                          |
| 684                 | 6766            | 2                                | 30                           |
| 685                 | 6783            | 2                                | 51                           |
| 686                 | 6800            | 2                                | 208                          |
| 687                 | 6817            | 2                                | 76                           |
| 688                 | 6834            | 2                                | 30                           |
| 689                 | 6851            | 2                                | 76                           |
| 690                 | 6868            | 2                                | 77                           |
| 691                 | 6886            | 2                                | 43                           |
| 692                 | 6903            | 2                                | 40                           |
| 693                 | 6920            | 2                                | 69                           |
| 694                 | 6938            | 2                                | 61                           |
| 695                 | 6955            | 2                                | 58                           |
| 696                 | 6972            | 2                                | 67                           |
| 697                 | 6990            | 2                                | 46                           |
| 698                 | 7007            | 2                                | 53                           |
| 699                 | 7025            | 2                                | 35                           |
| 700                 | 7042            | 2                                | 37                           |
| 701                 | 7060            | 2                                | 27                           |
| 702                 | 7078            | 2                                | 58                           |
| 703                 | 7095            | 2                                | 50                           |
| 704                 | 7113            | 2                                | 54                           |
| 705                 | 7131            | 2                                | 48                           |
| 706                 | 7149            | 2                                | 54                           |
| 707                 | 7166            | 2                                | 35                           |
| 708                 | 7184            | 2                                | 49                           |
| 709                 | 7202            | 2                                | 56                           |
| 710                 | 7220            | 2                                | 31                           |
| 711                 | 7238            | 2                                | 54                           |
| 712                 | 7256            | 2                                | 29                           |
| 713                 | 7274            | 2                                | 61                           |
| 714                 | 7292            | 2                                | 51                           |
| 715                 | 7310            | 2                                | 57                           |
| 716                 | 7329            | 2                                | 46                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 717                 | 7347            | 2                                | 141                          |
| 718                 | 7365            | 2                                | 51                           |
| 719                 | 7383            | 2                                | 29                           |
| 720                 | 7401            | 2                                | 38                           |
| 721                 | 7420            | 2                                | 45                           |
| 722                 | 7438            | 2                                | 44                           |
| 723                 | 7456            | 2                                | 47                           |
| 724                 | 7475            | 2                                | 57                           |
| 725                 | 7493            | 2                                | 30                           |
| 726                 | 7511            | 2                                | 33                           |
| 727                 | 7530            | 2                                | 41                           |
| 728                 | 7548            | 2                                | 48                           |
| 729                 | 7567            | 2                                | 30                           |
| 730                 | 7585            | 2                                | 35                           |
| 731                 | 7604            | 2                                | 27                           |
| 732                 | 7622            | 2                                | 45                           |
| 733                 | 7640            | 2                                | 50                           |
| 734                 | 7659            | 2                                | 48                           |
| 735                 | 7677            | 2                                | 30                           |
| 736                 | 7696            | 2                                | 37                           |
| 737                 | 7714            | 2                                | 48                           |
| 738                 | 7733            | 2                                | 19                           |
| 739                 | 7751            | 2                                | 76                           |
| 740                 | 7770            | 2                                | 19                           |
| 741                 | 7788            | 2                                | 15                           |
| 742                 | 7807            | 2                                | 11                           |
| 743                 | 7825            | 2                                | 11                           |
| 744                 | 7844            | 2                                | 5                            |
| 745                 | 7862            | 2                                | 10                           |
| 746                 | 7881            | 2                                | 17                           |
| 747                 | 7899            | 2                                | 25                           |
| 748                 | 7918            | 2                                | 21                           |
| 749                 | 7936            | 2                                | 13                           |
| 750                 | 7954            | 2                                | 25                           |
| 751                 | 7973            | 2                                | 3                            |
| 752                 | 7991            | 2                                | 32                           |
| 753                 | 8010            | 2                                | 36                           |
| 754                 | 8028            | 2                                | 22                           |
| 755                 | 8047            | 2                                | 21                           |
| 756                 | 8065            | 2                                | 58                           |
| 757                 | 8084            | 2                                | 29                           |
| 758                 | 8102            | 2                                | 39                           |
| 759                 | 8120            | 2                                | 14                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 760                 | 8139            | 2                                | 40                           |
| 761                 | 8157            | 2                                | 6                            |
| 762                 | 8176            | 2                                | 4                            |
| 763                 | 8194            | 2                                | 24                           |
| 764                 | 8212            | 2                                | 19                           |
| 765                 | 8231            | 2                                | 17                           |
| 766                 | 8249            | 2                                | 19                           |
| 767                 | 8267            | 2                                | 33                           |
| 768                 | 8286            | 2                                | 34                           |
| 769                 | 8304            | 2                                | 45                           |
| 770                 | 8322            | 2                                | 11                           |
| 771                 | 8340            | 2                                | 24                           |
| 772                 | 8359            | 2                                | 67                           |
| 773                 | 8377            | 2                                | 46                           |
| 774                 | 8395            | 2                                | 26                           |
| 775                 | 8413            | 2                                | 20                           |
| 776                 | 8432            | 2                                | 26                           |
| 777                 | 8450            | 2                                | 25                           |
| 778                 | 8468            | 2                                | 18                           |
| 779                 | 8486            | 2                                | 22                           |
| 780                 | 8504            | 2                                | 22                           |
| 781                 | 8522            | 2                                | 16                           |
| 782                 | 8540            | 2                                | 58                           |
| 783                 | 8559            | 2                                | 20                           |
| 784                 | 8577            | 2                                | 15                           |
| 785                 | 8595            | 2                                | 15                           |
| 786                 | 8613            | 2                                | 17                           |
| 787                 | 8631            | 2                                | 18                           |
| 788                 | 8649            | 2                                | 16                           |
| 789                 | 8667            | 2                                | 17                           |
| 790                 | 8684            | 2                                | 7                            |
| 791                 | 8702            | 2                                | 8                            |
| 792                 | 8720            | 2                                | 26                           |
| 793                 | 8738            | 2                                | 8                            |
| 794                 | 8756            | 2                                | 22                           |
| 795                 | 8774            | 2                                | 16                           |
| 796                 | 8792            | 2                                | 21                           |
| 797                 | 8809            | 2                                | 24                           |
| 798                 | 8827            | 2                                | 30                           |
| 799                 | 8845            | 2                                | 29                           |
| 800                 | 8862            | 2                                | 24                           |
| 801                 | 8880            | 2                                | 24                           |
| 802                 | 8898            | 2                                | 21                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 803                 | 8915            | 2                                | 15                           |
| 804                 | 8933            | 2                                | 32                           |
| 805                 | 8950            | 2                                | 13                           |
| 806                 | 8968            | 2                                | 27                           |
| 807                 | 8985            | 2                                | 43                           |
| 808                 | 9003            | 2                                | 17                           |
| 809                 | 9020            | 2                                | 147                          |
| 810                 | 9038            | 2                                | 18                           |
| 811                 | 9055            | 2                                | 13                           |
| 812                 | 9072            | 2                                | 15                           |
| 813                 | 9089            | 2                                | 12                           |
| 814                 | 9107            | 2                                | 21                           |
| 815                 | 9124            | 2                                | 29                           |
| 816                 | 9141            | 2                                | 10                           |
| 817                 | 9158            | 2                                | 13                           |
| 818                 | 9175            | 2                                | 23                           |
| 819                 | 9192            | 2                                | 9                            |
| 820                 | 9209            | 2                                | 15                           |
| 821                 | 9226            | 2                                | 20                           |
| 822                 | 9243            | 2                                | 32                           |
| 823                 | 9260            | 2                                | 55                           |
| 824                 | 9277            | 2                                | 21                           |
| 825                 | 9294            | 2                                | 14                           |
| 826                 | 9311            | 2                                | 25                           |
| 827                 | 9328            | 2                                | 27                           |
| 828                 | 9344            | 2                                | 9                            |
| 829                 | 9361            | 2                                | 6                            |
| 830                 | 9378            | 2                                | 29                           |
| 831                 | 9394            | 2                                | 36                           |
| 832                 | 9411            | 2                                | 29                           |
| 833                 | 9427            | 2                                | 95                           |
| 834                 | 9444            | 2                                | 30                           |
| 835                 | 9460            | 2                                | 23                           |
| 836                 | 9476            | 2                                | 31                           |
| 837                 | 9493            | 2                                | 20                           |
| 838                 | 9509            | 2                                | 15                           |
| 839                 | 9525            | 2                                | 20                           |
| 840                 | 9541            | 2                                | 20                           |
| 841                 | 9558            | 2                                | 37                           |
| 842                 | 9574            | 2                                | 50                           |
| 843                 | 9590            | 2                                | 66                           |
| 844                 | 9606            | 2                                | 28                           |
| 845                 | 9622            | 2                                | 26                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 846                 | 9638            | 2                                | 34                           |
| 847                 | 9653            | 2                                | 12                           |
| 848                 | 9669            | 2                                | 35                           |
| 849                 | 9685            | 2                                | 12                           |
| 850                 | 9701            | 2                                | 15                           |
| 851                 | 9716            | 2                                | 14                           |
| 852                 | 9732            | 2                                | 32                           |
| 853                 | 9747            | 2                                | 18                           |
| 854                 | 9763            | 2                                | 22                           |
| 855                 | 9778            | 2                                | 10                           |
| 856                 | 9794            | 2                                | 35                           |
| 857                 | 9809            | 2                                | 15                           |
| 858                 | 9824            | 2                                | 27                           |
| 859                 | 9840            | 2                                | 20                           |
| 860                 | 9855            | 2                                | 48                           |
| 861                 | 9870            | 2                                | 18                           |
| 862                 | 9885            | 2                                | 28                           |
| 863                 | 9900            | 2                                | 24                           |
| 864                 | 9915            | 2                                | 21                           |
| 865                 | 9930            | 2                                | 13                           |
| 866                 | 9944            | 2                                | 7                            |
| 867                 | 9959            | 2                                | 37                           |
| 868                 | 9974            | 2                                | 15                           |
| 869                 | 9989            | 2                                | 4                            |
| 870                 | 10003           | 2                                | 14                           |
| 871                 | 10018           | 2                                | 13                           |
| 872                 | 10032           | 2                                | 12                           |
| 873                 | 10046           | 2                                | 9                            |
| 874                 | 10061           | 2                                | 11                           |
| 875                 | 10075           | 2                                | 9                            |
| 876                 | 10089           | 2                                | 22                           |
| 877                 | 10103           | 2                                | 41                           |
| 878                 | 10117           | 2                                | 13                           |
| 879                 | 10131           | 2                                | 24                           |
| 880                 | 10145           | 2                                | 1                            |
| 881                 | 10159           | 2                                | 9                            |
| 882                 | 10173           | 2                                | 11                           |
| 883                 | 10187           | 2                                | 8                            |
| 884                 | 10200           | 2                                | 2                            |
| 885                 | 10214           | 2                                | 6                            |
| 886                 | 10228           | 2                                | 10                           |
| 887                 | 10241           | 2                                | 8                            |
| 888                 | 10254           | 2                                | 32                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 889                 | 10268           | 2                                | 7                            |
| 890                 | 10281           | 2                                | 19                           |
| 891                 | 10294           | 2                                | 18                           |
| 892                 | 10307           | 2                                | 10                           |
| 893                 | 10320           | 2                                | 34                           |
| 894                 | 10333           | 2                                | 25                           |
| 895                 | 10346           | 2                                | 27                           |
| 896                 | 10359           | 2                                | 19                           |
| 897                 | 10372           | 2                                | 2                            |
| 898                 | 10384           | 2                                | 17                           |
| 899                 | 10397           | 2                                | 8                            |
| 900                 | 10410           | 2                                | 4                            |
| 901                 | 10422           | 2                                | 0                            |
| 902                 | 10434           | 2                                | 5                            |
| 903                 | 10447           | -999                             | -999                         |
| 904                 | 10459           | -999                             | -999                         |
| 905                 | 10471           | 2                                | 12                           |
| 906                 | 10483           | 2                                | 8                            |
| 907                 | 10495           | 2                                | 6                            |
| 908                 | 10507           | 2                                | 14                           |
| 909                 | 10519           | 2                                | 15                           |
| 910                 | 10531           | 2                                | 31                           |
| 911                 | 10542           | 2                                | 7                            |
| 912                 | 10554           | 2                                | 4                            |
| 913                 | 10565           | 2                                | 11                           |
| 914                 | 10577           | 2                                | 2                            |
| 915                 | 10588           | 2                                | 10                           |
| 916                 | 10599           | 2                                | 14                           |
| 917                 | 10611           | 2                                | 8                            |
| 918                 | 10622           | 2                                | 18                           |
| 919                 | 10633           | 2                                | 37                           |
| 920                 | 10644           | 2                                | 21                           |
| 921                 | 10655           | 2                                | 9                            |
| 922                 | 10665           | 2                                | 18                           |
| 923                 | 10676           | 2                                | 25                           |
| 924                 | 10687           | 2                                | 20                           |
| 925                 | 10697           | 2                                | 12                           |
| 926                 | 10708           | 2                                | 25                           |
| 927                 | 10718           | 2                                | 14                           |
| 928                 | 10729           | 2                                | 13                           |
| 929                 | 10739           | 2                                | 14                           |
| 930                 | 10749           | 2                                | 8                            |
| 931                 | 10760           | 2                                | 16                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 932                 | 10770           | 2                                | 14                           |
| 933                 | 10780           | 2                                | 13                           |
| 934                 | 10790           | 2                                | 17                           |
| 935                 | 10800           | 2                                | 18                           |
| 936                 | 10809           | 2                                | 11                           |
| 937                 | 10819           | 2                                | 11                           |
| 938                 | 10829           | 2                                | 10                           |
| 939                 | 10839           | 2                                | 11                           |
| 940                 | 10848           | 2                                | 4                            |
| 941                 | 10858           | 2                                | 14                           |
| 942                 | 10867           | 2                                | 7                            |
| 943                 | 10877           | 2                                | 6                            |
| 944                 | 10886           | 2                                | 39                           |
| 945                 | 10895           | 2                                | 11                           |
| 946                 | 10904           | 2                                | 19                           |
| 947                 | 10914           | 2                                | 18                           |
| 948                 | 10923           | 2                                | 15                           |
| 949                 | 10932           | 2                                | 9                            |
| 950                 | 10941           | 2                                | 5                            |
| 951                 | 10950           | 2                                | 7                            |
| 952                 | 10959           | -999                             | -999                         |
| 953                 | 10967           | 2                                | 16                           |
| 954                 | 10976           | 2                                | 13                           |
| 955                 | 10985           | 2                                | 9                            |
| 956                 | 10994           | 2                                | 6                            |
| 957                 | 11002           | 2                                | 10                           |
| 958                 | 11011           | 2                                | 13                           |
| 959                 | 11019           | -999                             | -999                         |
| 960                 | 11028           | 2                                | 14                           |
| 961                 | 11036           | 2                                | 9                            |
| 962                 | 11045           | 2                                | 5                            |
| 963                 | 11053           | 2                                | 6                            |
| 964                 | 11061           | 2                                | 14                           |
| 965                 | 11070           | 2                                | 4                            |
| 966                 | 11078           | 2                                | 7                            |
| 967                 | 11086           | 2                                | 13                           |
| 968                 | 11094           | 2                                | 10                           |
| 969                 | 11102           | 2                                | 12                           |
| 970                 | 11110           | 2                                | 7                            |
| 971                 | 11118           | 2                                | 8                            |
| 972                 | 11126           | 2                                | 14                           |
| 973                 | 11134           | 2                                | 10                           |
| 974                 | 11142           | 2                                | 11                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 975                 | 11150           | 2                                | 4                            |
| 976                 | 11157           | 2                                | 13                           |
| 977                 | 11165           | 2                                | 19                           |
| 978                 | 11173           | 2                                | 8                            |
| 979                 | 11180           | 2                                | 14                           |
| 980                 | 11188           | 2                                | 6                            |
| 981                 | 11196           | 2                                | 11                           |
| 982                 | 11203           | 2                                | 16                           |
| 983                 | 11211           | 2                                | 16                           |
| 984                 | 11218           | 2                                | 4                            |
| 985                 | 11226           | 2                                | 15                           |
| 986                 | 11233           | 2                                | 8                            |
| 987                 | 11240           | 2                                | 12                           |
| 988                 | 11248           | 2                                | 10                           |
| 989                 | 11255           | 2                                | 13                           |
| 990                 | 11262           | 2                                | 19                           |
| 991                 | 11270           | 2                                | 18                           |
| 992                 | 11277           | 2                                | 18                           |
| 993                 | 11284           | 2                                | 20                           |
| 994                 | 11291           | 2                                | 22                           |
| 995                 | 11298           | 2                                | 16                           |
| 996                 | 11306           | 2                                | 10                           |
| 997                 | 11313           | 2                                | 7                            |
| 998                 | 11320           | 2                                | 13                           |
| 999                 | 11327           | 2                                | 9                            |
| 1000                | 11334           | 2                                | 6                            |
| 1001                | 11341           | 2                                | 7                            |
| 1002                | 11348           | 2                                | 3                            |
| 1003                | 11355           | 2                                | 18                           |
| 1004                | 11362           | 2                                | 19                           |
| 1005                | 11369           | 2                                | 7                            |
| 1006                | 11375           | 2                                | 5                            |
| 1007                | 11382           | 2                                | 23                           |
| 1008                | 11389           | 2                                | 6                            |
| 1009                | 11396           | 2                                | 12                           |
| 1010                | 11403           | 2                                | 4                            |
| 1011                | 11410           | 2                                | 1                            |
| 1012                | 11416           | 2                                | 8                            |
| 1013                | 11423           | 2                                | 5                            |
| 1014                | 11430           | 2                                | 2                            |
| 1015                | 11437           | 2                                | 12                           |
| 1016                | 11443           | 2                                | 1                            |
| 1017                | 11450           | 2                                | 4                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 1018                | 11457           | 2                                | 4                            |
| 1019                | 11463           | 2                                | 2                            |
| 1020                | 11470           | 2                                | 13                           |
| 1021                | 11477           | 2                                | 7                            |
| 1022                | 11483           | 2                                | 9                            |
| 1023                | 11490           | 2                                | 4                            |
| 1024                | 11497           | 2                                | 9                            |
| 1025                | 11503           | 2                                | 4                            |
| 1026                | 11510           | 2                                | 8                            |
| 1027                | 11517           | 2                                | 4                            |
| 1028                | 11523           | 2                                | 5                            |
| 1029                | 11530           | 2                                | 5                            |
| 1030                | 11536           | 2                                | 8                            |
| 1031                | 11543           | 2                                | 11                           |
| 1032                | 11550           | 2                                | 8                            |
| 1033                | 11556           | 2                                | 5                            |
| 1034                | 11563           | 2                                | 5                            |
| 1035                | 11569           | 2                                | 4                            |
| 1036                | 11576           | 2                                | 6                            |
| 1037                | 11582           | 2                                | 12                           |
| 1038                | 11589           | 2                                | 6                            |
| 1039                | 11596           | 2                                | 10                           |
| 1040                | 11602           | 2                                | 4                            |
| 1041                | 11609           | 2                                | 7                            |
| 1042                | 11615           | 2                                | 5                            |
| 1043                | 11622           | 2                                | 4                            |
| 1044                | 11629           | 2                                | 2                            |
| 1045                | 11635           | 2                                | 4                            |
| 1046                | 11642           | 2                                | 0                            |
| 1047                | 11648           | 2                                | 7                            |
| 1048                | 11655           | 2                                | 5                            |
| 1049                | 11662           | 2                                | 3                            |
| 1050                | 11668           | 2                                | 2                            |
| 1051                | 11675           | 2                                | 2                            |
| 1052                | 11682           | 2                                | 6                            |
| 1053                | 11688           | 2                                | 5                            |
| 1054                | 11695           | 2                                | 8                            |
| 1055                | 11702           | 2                                | 3                            |
| 1056                | 11708           | 2                                | 8                            |
| 1057                | 11715           | 2                                | 8                            |
| 1058                | 11722           | 2                                | 4                            |
| 1059                | 11728           | 2                                | 5                            |
| 1060                | 11735           | 2                                | 11                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 1061                | 11742           | 2                                | 1                            |
| 1062                | 11749           | 2                                | 10                           |
| 1063                | 11756           | 2                                | 14                           |
| 1064                | 11762           | 2                                | 4                            |
| 1065                | 11769           | 2                                | 6                            |
| 1066                | 11776           | 2                                | 13                           |
| 1067                | 11783           | 2                                | 9                            |
| 1068                | 11790           | 2                                | 4                            |
| 1069                | 11797           | 2                                | 1                            |
| 1070                | 11804           | 2                                | 5                            |
| 1071                | 11811           | 2                                | 8                            |
| 1072                | 11818           | 2                                | 4                            |
| 1073                | 11825           | 2                                | 18                           |
| 1074                | 11832           | 2                                | 4                            |
| 1075                | 11839           | 2                                | 7                            |
| 1076                | 11846           | 2                                | 6                            |
| 1077                | 11853           | 2                                | 17                           |
| 1078                | 11860           | 2                                | 4                            |
| 1079                | 11867           | 2                                | 10                           |
| 1080                | 11874           | 2                                | 16                           |
| 1081                | 11881           | 2                                | 10                           |
| 1082                | 11889           | 2                                | 8                            |
| 1083                | 11896           | 2                                | 7                            |
| 1084                | 11903           | 2                                | 5                            |
| 1085                | 11910           | 2                                | 5                            |
| 1086                | 11918           | 2                                | 4                            |
| 1087                | 11925           | 2                                | 7                            |
| 1088                | 11932           | 2                                | 5                            |
| 1089                | 11940           | 2                                | 2                            |
| 1090                | 11947           | 2                                | 4                            |
| 1091                | 11955           | 2                                | 4                            |
| 1092                | 11962           | 2                                | 1                            |
| 1093                | 11969           | 2                                | 2                            |
| 1094                | 11977           | 2                                | 3                            |
| 1095                | 11984           | 2                                | 9                            |
| 1096                | 11992           | 2                                | 3                            |
| 1097                | 12000           | 2                                | 4                            |
| 1098                | 12007           | 2                                | 6                            |
| 1099                | 12015           | 2                                | 2                            |
| 1100                | 12022           | 2                                | 6                            |
| 1101                | 12030           | 2                                | 7                            |
| 1102                | 12038           | 2                                | 8                            |
| 1103                | 12045           | 2                                | 4                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 1104                | 12053           | 2                                | 3                            |
| 1105                | 12061           | 2                                | 2                            |
| 1106                | 12068           | 2                                | 8                            |
| 1107                | 12076           | 2                                | 5                            |
| 1108                | 12084           | 2                                | 1                            |
| 1109                | 12092           | 2                                | 0                            |
| 1110                | 12099           | 2                                | 1                            |
| 1111                | 12107           | 2                                | 4                            |
| 1112                | 12115           | 2                                | 4                            |
| 1113                | 12123           | 2                                | 4                            |
| 1114                | 12131           | 2                                | 1                            |
| 1115                | 12139           | 2                                | 2                            |
| 1116                | 12146           | 2                                | 2                            |
| 1117                | 12154           | 2                                | 3                            |
| 1118                | 12162           | 2                                | 4                            |
| 1119                | 12170           | 2                                | 1                            |
| 1120                | 12178           | 2                                | 4                            |
| 1121                | 12186           | 2                                | 1                            |
| 1122                | 12194           | 2                                | 3                            |
| 1123                | 12202           | 2                                | 7                            |
| 1124                | 12210           | 2                                | 5                            |
| 1125                | 12218           | 2                                | 2                            |
| 1126                | 12226           | 2                                | 8                            |
| 1127                | 12234           | 2                                | 16                           |
| 1128                | 12242           | 2                                | 115                          |
| 1129                | 12250           | 2                                | 5                            |
| 1130                | 12258           | 2                                | 3                            |
| 1131                | 12266           | 2                                | 5                            |
| 1132                | 12274           | 2                                | 11                           |
| 1133                | 12282           | 2                                | 6                            |
| 1134                | 12290           | 2                                | 2                            |
| 1135                | 12299           | 2                                | 3                            |
| 1136                | 12307           | 2                                | 4                            |
| 1137                | 12315           | 2                                | 8                            |
| 1138                | 12323           | 2                                | 13                           |
| 1139                | 12331           | 2                                | 13                           |
| 1140                | 12339           | 2                                | 6                            |
| 1141                | 12347           | 2                                | 9                            |
| 1142                | 12356           | 2                                | 2                            |
| 1143                | 12364           | 2                                | 4                            |
| 1144                | 12372           | 2                                | 0                            |
| 1145                | 12380           | 2                                | 4                            |
| 1146                | 12388           | 2                                | 3                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 1147                | 12397           | 2                                | 5                            |
| 1148                | 12405           | 2                                | 8                            |
| 1149                | 12413           | 2                                | 12                           |
| 1150                | 12421           | 2                                | 5                            |
| 1151                | 12429           | 2                                | 6                            |
| 1152                | 12438           | 2                                | 2                            |
| 1153                | 12446           | 2                                | 1                            |
| 1154                | 12454           | 2                                | 5                            |
| 1155                | 12462           | 2                                | 6                            |
| 1156                | 12471           | 2                                | 10                           |
| 1157                | 12479           | 2                                | 3                            |
| 1158                | 12487           | 2                                | 3                            |
| 1159                | 12495           | 2                                | 4                            |
| 1160                | 12504           | 2                                | 11                           |
| 1161                | 12512           | 2                                | 17                           |
| 1162                | 12520           | 2                                | 10                           |
| 1163                | 12528           | 2                                | 4                            |
| 1164                | 12537           | 2                                | 15                           |
| 1165                | 12545           | 2                                | 20                           |
| 1166                | 12553           | 2                                | 19                           |
| 1167                | 12561           | 2                                | 47                           |
| 1168                | 12570           | 2                                | 7                            |
| 1169                | 12578           | 2                                | 9                            |
| 1170                | 12586           | 2                                | 8                            |
| 1171                | 12595           | 2                                | 15                           |
| 1172                | 12603           | 2                                | 11                           |
| 1173                | 12611           | 2                                | 21                           |
| 1174                | 12619           | 2                                | 12                           |
| 1175                | 12628           | 2                                | 14                           |
| 1176                | 12636           | 2                                | 7                            |
| 1177                | 12644           | 2                                | 3                            |
| 1178                | 12652           | 2                                | 6                            |
| 1179                | 12661           | 2                                | 8                            |
| 1180                | 12669           | 2                                | 9                            |
| 1181                | 12677           | 2                                | 8                            |
| 1182                | 12685           | 2                                | 2                            |
| 1183                | 12694           | 2                                | 0                            |
| 1184                | 12702           | 2                                | 2                            |
| 1185                | 12710           | 2                                | 8                            |
| 1186                | 12718           | 2                                | 5                            |
| 1187                | 12727           | 2                                | 5                            |
| 1188                | 12735           | 2                                | 2                            |
| 1189                | 12743           | 2                                | 1                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 1190                | 12751           | 2                                | 7                            |
| 1191                | 12760           | 2                                | 5                            |
| 1192                | 12768           | 2                                | 7                            |
| 1193                | 12776           | 2                                | 6                            |
| 1194                | 12784           | 2                                | 1                            |
| 1195                | 12792           | 2                                | 10                           |
| 1196                | 12801           | 2                                | 5                            |
| 1197                | 12809           | 2                                | 12                           |
| 1198                | 12817           | 2                                | 22                           |
| 1199                | 12825           | 2                                | 2                            |
| 1200                | 12833           | 2                                | 1                            |
| 1201                | 12841           | 2                                | 1                            |
| 1202                | 12849           | 2                                | 2                            |
| 1203                | 12858           | 2                                | 1                            |
| 1204                | 12866           | 2                                | 1                            |
| 1205                | 12874           | 2                                | 2                            |
| 1206                | 12882           | 2                                | 13                           |
| 1207                | 12890           | 2                                | 3                            |
| 1208                | 12898           | 2                                | 8                            |
| 1209                | 12906           | 2                                | 10                           |
| 1210                | 12914           | 2                                | 11                           |
| 1211                | 12922           | 2                                | 10                           |
| 1212                | 12930           | 2                                | 3                            |
| 1213                | 12938           | 2                                | 5                            |
| 1214                | 12946           | 2                                | 12                           |
| 1215                | 12954           | 2                                | 5                            |
| 1216                | 12962           | 2                                | 4                            |
| 1217                | 12970           | 2                                | 4                            |
| 1218                | 12978           | 2                                | 4                            |
| 1219                | 12986           | 2                                | 9                            |
| 1220                | 12994           | 2                                | 7                            |
| 1221                | 13002           | 2                                | 4                            |
| 1222                | 13010           | 2                                | 8                            |
| 1223                | 13018           | 2                                | 10                           |
| 1224                | 13025           | 2                                | 9                            |
| 1225                | 13033           | 2                                | 15                           |
| 1226                | 13041           | 2                                | 8                            |
| 1227                | 13049           | 2                                | 9                            |
| 1228                | 13057           | 2                                | 4                            |
| 1229                | 13064           | 2                                | 4                            |
| 1230                | 13072           | 2                                | 10                           |
| 1231                | 13080           | 2                                | 9                            |
| 1232                | 13088           | 2                                | 4                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 1233                | 13095           | 2                                | 3                            |
| 1234                | 13103           | 2                                | 4                            |
| 1235                | 13111           | 2                                | 3                            |
| 1236                | 13118           | 2                                | 7                            |
| 1237                | 13126           | 2                                | 3                            |
| 1238                | 13134           | 2                                | 7                            |
| 1239                | 13141           | 2                                | 22                           |
| 1240                | 13149           | 2                                | 6                            |
| 1241                | 13157           | 2                                | 5                            |
| 1242                | 13164           | 2                                | 4                            |
| 1243                | 13172           | 2                                | 8                            |
| 1244                | 13179           | 2                                | 3                            |
| 1245                | 13187           | 2                                | 3                            |
| 1246                | 13194           | 2                                | 9                            |
| 1247                | 13201           | 2                                | 2                            |
| 1248                | 13209           | 2                                | 6                            |
| 1249                | 13216           | 2                                | 6                            |
| 1250                | 13224           | 2                                | 5                            |
| 1251                | 13231           | 2                                | 3                            |
| 1252                | 13238           | 2                                | 4                            |
| 1253                | 13246           | 2                                | 4                            |
| 1254                | 13253           | 2                                | 1                            |
| 1255                | 13260           | 2                                | 8                            |
| 1256                | 13267           | 2                                | 10                           |
| 1257                | 13275           | 2                                | 10                           |
| 1258                | 13282           | 2                                | 2                            |
| 1259                | 13289           | 2                                | 2                            |
| 1260                | 13296           | 2                                | 6                            |
| 1261                | 13303           | 2                                | 5                            |
| 1262                | 13310           | 2                                | 3                            |
| 1263                | 13317           | 2                                | 11                           |
| 1264                | 13324           | 2                                | 4                            |
| 1265                | 13331           | 2                                | 4                            |
| 1266                | 13338           | 2                                | 5                            |
| 1267                | 13345           | 2                                | 5                            |
| 1268                | 13352           | 2                                | 4                            |
| 1269                | 13359           | 2                                | 5                            |
| 1270                | 13366           | 2                                | 5                            |
| 1271                | 13373           | 2                                | 6                            |
| 1272                | 13380           | 2                                | 11                           |
| 1273                | 13387           | 2                                | 19                           |
| 1274                | 13393           | 2                                | 8                            |
| 1275                | 13400           | 2                                | 1                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 1276                | 13407           | 2                                | 3                            |
| 1277                | 13413           | 2                                | 5                            |
| 1278                | 13420           | 2                                | 4                            |
| 1279                | 13427           | 2                                | 6                            |
| 1280                | 13433           | 2                                | 2                            |
| 1281                | 13440           | 2                                | 4                            |
| 1282                | 13446           | 2                                | 3                            |
| 1283                | 13453           | 2                                | 16                           |
| 1284                | 13459           | 2                                | 7                            |
| 1285                | 13466           | 2                                | 11                           |
| 1286                | 13472           | 2                                | 2                            |
| 1287                | 13479           | 2                                | 6                            |
| 1288                | 13485           | 2                                | 3                            |
| 1289                | 13491           | 2                                | 6                            |
| 1290                | 13497           | 2                                | 9                            |
| 1291                | 13504           | 2                                | 6                            |
| 1292                | 13510           | 2                                | 4                            |
| 1293                | 13516           | 2                                | 4                            |
| 1294                | 13522           | 2                                | 7                            |
| 1295                | 13528           | 2                                | 8                            |
| 1296                | 13534           | 2                                | 4                            |
| 1297                | 13540           | -999                             | -999                         |
| 1298                | 13546           | -999                             | -999                         |
| 1299                | 13552           | -999                             | -999                         |
| 1300                | 13558           | -999                             | -999                         |
| 1301                | 13564           | -999                             | -999                         |
| 1302                | 13570           | -999                             | -999                         |
| 1303                | 13576           | -999                             | -999                         |
| 1304                | 13582           | -999                             | -999                         |
| 1305                | 13587           | -999                             | -999                         |
| 1306                | 13593           | -999                             | -999                         |
| 1307                | 13599           | -999                             | -999                         |
| 1308                | 13604           | -999                             | -999                         |
| 1309                | 13610           | -999                             | -999                         |
| 1310                | 13615           | -999                             | -999                         |
| 1311                | 13621           | -999                             | -999                         |
| 1312                | 13626           | -999                             | -999                         |
| 1313                | 13632           | -999                             | -999                         |
| 1314                | 13637           | -999                             | -999                         |
| 1315                | 13643           | -999                             | -999                         |
| 1316                | 13648           | -999                             | -999                         |
| 1317                | 13653           | -999                             | -999                         |
| 1318                | 13658           | 2                                | 4                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 1319                | 13664           | 2                                | 7                            |
| 1320                | 13669           | 2                                | 5                            |
| 1321                | 13674           | 2                                | 9                            |
| 1322                | 13679           | 2                                | 4                            |
| 1323                | 13684           | 2                                | 9                            |
| 1324                | 13689           | 2                                | 3                            |
| 1325                | 13694           | 2                                | 2                            |
| 1326                | 13699           | 2                                | 18                           |
| 1327                | 13704           | 2                                | 11                           |
| 1328                | 13709           | 2                                | 6                            |
| 1329                | 13714           | 2                                | 1                            |
| 1330                | 13718           | 2                                | 5                            |
| 1331                | 13723           | 2                                | 5                            |
| 1332                | 13728           | 2                                | 6                            |
| 1333                | 13733           | 2                                | 6                            |
| 1334                | 13737           | 2                                | 8                            |
| 1335                | 13742           | 2                                | 1                            |
| 1336                | 13746           | 2                                | 6                            |
| 1337                | 13751           | 2                                | 1                            |
| 1338                | 13755           | 2                                | 5                            |
| 1339                | 13760           | 2                                | 3                            |
| 1340                | 13764           | 2                                | 6                            |
| 1341                | 13769           | 2                                | 3                            |
| 1342                | 13773           | 2                                | 3                            |
| 1343                | 13778           | 2                                | 6                            |
| 1344                | 13782           | 2                                | 3                            |
| 1345                | 13786           | 2                                | 2                            |
| 1346                | 13790           | 2                                | 4                            |
| 1347                | 13795           | 2                                | 4                            |
| 1348                | 13799           | 2                                | 4                            |
| 1349                | 13803           | 2                                | 8                            |
| 1350                | 13807           | 2                                | 1                            |
| 1351                | 13811           | 2                                | 8                            |
| 1352                | 13815           | 2                                | 4                            |
| 1353                | 13819           | 2                                | 6                            |
| 1354                | 13823           | 2                                | 6                            |
| 1355                | 13827           | 2                                | 2                            |
| 1356                | 13831           | 2                                | 5                            |
| 1357                | 13835           | 2                                | 5                            |
| 1358                | 13839           | 2                                | 2                            |
| 1359                | 13843           | 2                                | 7                            |
| 1360                | 13846           | 2                                | 9                            |
| 1361                | 13850           | 2                                | 8                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 1362                | 13854           | 2                                | 9                            |
| 1363                | 13858           | 2                                | 18                           |
| 1364                | 13861           | 2                                | 9                            |
| 1365                | 13865           | 2                                | 11                           |
| 1366                | 13868           | 2                                | 7                            |
| 1367                | 13872           | 2                                | 9                            |
| 1368                | 13876           | 2                                | 6                            |
| 1369                | 13879           | 2                                | 6                            |
| 1370                | 13883           | 2                                | 3                            |
| 1371                | 13886           | 2                                | 3                            |
| 1372                | 13889           | 2                                | 2                            |
| 1373                | 13893           | 2                                | 3                            |
| 1374                | 13896           | 2                                | 3                            |
| 1375                | 13900           | 2                                | 2                            |
| 1376                | 13903           | 2                                | 12                           |
| 1377                | 13906           | 2                                | 5                            |
| 1378                | 13909           | 2                                | 13                           |
| 1379                | 13913           | 2                                | 8                            |
| 1380                | 13916           | 2                                | 2                            |
| 1381                | 13919           | 2                                | 5                            |
| 1382                | 13922           | 2                                | 4                            |
| 1383                | 13925           | 2                                | 8                            |
| 1384                | 13928           | 2                                | 8                            |
| 1385                | 13931           | 2                                | 3                            |
| 1386                | 13934           | 2                                | 5                            |
| 1387                | 13937           | 2                                | 5                            |
| 1388                | 13940           | 2                                | 3                            |
| 1389                | 13943           | 2                                | 8                            |
| 1390                | 13946           | 2                                | 5                            |
| 1391                | 13949           | 2                                | 6                            |
| 1392                | 13952           | 2                                | 8                            |
| 1393                | 13955           | 2                                | 12                           |
| 1394                | 13958           | 2                                | 4                            |
| 1395                | 13961           | 2                                | 8                            |
| 1396                | 13963           | 2                                | 8                            |
| 1397                | 13966           | 2                                | 5                            |
| 1398                | 13969           | 2                                | 7                            |
| 1399                | 13971           | 2                                | 10                           |
| 1400                | 13974           | 2                                | 5                            |
| 1401                | 13977           | 2                                | 8                            |
| 1402                | 13979           | 2                                | 4                            |
| 1403                | 13982           | 2                                | 8                            |
| 1404                | 13985           | 2                                | 4                            |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 1405                | 13987           | 2                                | 7                            |
| 1406                | 13990           | 2                                | 2                            |
| 1407                | 13992           | 2                                | 27                           |
| 1408                | 13995           | 2                                | 7                            |
| 1409                | 13997           | 2                                | 3                            |
| 1410                | 13999           | 2                                | 3                            |
| 1411                | 14002           | 2                                | 5                            |
| 1412                | 14004           | 2                                | 7                            |
| 1413                | 14007           | 2                                | 5                            |
| 1414                | 14009           | 2                                | 4                            |
| 1415                | 14011           | 2                                | 2                            |
| 1416                | 14014           | 2                                | 1                            |
| 1417                | 14016           | 2                                | 5                            |
| 1418                | 14018           | 2                                | 7                            |
| 1419                | 14020           | 2                                | 11                           |
| 1420                | 14022           | 2                                | 4                            |
| 1421                | 14025           | 2                                | 4                            |
| 1422                | 14027           | 2                                | 2                            |
| 1423                | 14029           | 2                                | 5                            |
| 1424                | 14031           | 2                                | 2                            |
| 1425                | 14033           | 2                                | 5                            |
| 1426                | 14035           | 2                                | 15                           |
| 1427                | 14037           | 2                                | 15                           |
| 1428                | 14039           | 2                                | 16                           |
| 1429                | 14041           | 2                                | 12                           |
| 1430                | 14043           | 2                                | 10                           |
| 1431                | 14045           | 2                                | 7                            |
| 1432                | 14047           | 2                                | 4                            |
| 1433                | 14049           | 2                                | 4                            |
| 1434                | 14051           | 2                                | 5                            |
| 1435                | 14053           | 2                                | 6                            |
| 1436                | 14055           | 2                                | 6                            |
| 1437                | 14057           | 2                                | 5                            |
| 1438                | 14058           | 2                                | 5                            |
| 1439                | 14060           | 2                                | 14                           |
| 1440                | 14062           | 2                                | 6                            |
| 1441                | 14064           | 2                                | 3                            |
| 1442                | 14065           | 2                                | 7                            |
| 1443                | 14067           | 2                                | 25                           |
| 1444                | 14069           | 2                                | 21                           |
| 1445                | 14071           | 2                                | 5                            |
| 1446                | 14072           | 2                                | 7                            |
| 1447                | 14074           | 2                                | 17                           |

| Sediment Depth (cm) | Age (cal yr BP) | Sample volume (cm <sup>3</sup> ) | Charcoal Count (# particles) |
|---------------------|-----------------|----------------------------------|------------------------------|
| 1448                | 14076           | 2                                | 10                           |
| 1449                | 14077           | 2                                | 6                            |
| 1450                | 14079           | 2                                | 7                            |
| 1451                | 14080           | -999                             | -999                         |
| 1452                | 14082           | -999                             | -999                         |
| 1453                | 14084           | -999                             | -999                         |
| 1454                | 14085           | -999                             | -999                         |
| 1455                | 14087           | -999                             | -999                         |
| 1456                | 14088           | -999                             | -999                         |
| 1457                | 14090           | -999                             | -999                         |
| 1458                | 14091           | -999                             | -999                         |
| 1459                | 14093           | -999                             | -999                         |
| 1460                | 14094           | -999                             | -999                         |
| 1461                | 14095           | -999                             | -999                         |
| 1462                | 14097           | -999                             | -999                         |
| 1463                | 14098           | -999                             | -999                         |
| 1464                | 14100           | -999                             | -999                         |
| 1465                | 14101           | -999                             | -999                         |
| 1466                | 14102           | 2                                | 10                           |
| 1467                | 14104           | 2                                | 8                            |
| 1468                | 14105           | 2                                | 13                           |
| 1469                | 14106           | 2                                | 17                           |
| 1470                | 14107           | 2                                | 17                           |
| 1471                | 14109           | 2                                | 7                            |
| 1472                | 14110           | 2                                | 9                            |
| 1473                | 14111           | 2                                | 1                            |
| 1474                | 14112           | 2                                | 2                            |
| 1475                | 14114           | 2                                | 8                            |
| 1476                | 14115           | 2                                | 5                            |
| 1477                | 14116           | 2                                | 4                            |
| 1478                | 14117           | 2                                | 5                            |
| 1479                | 14118           | 2                                | 3                            |
| 1480                | 14120           | 2                                | 2                            |

APPENDIX C  
SITES VISITED FOR THESIS CHAPTER 2

| Name                | Lat    | Long     | Cored? | Water Depth (m) |
|---------------------|--------|----------|--------|-----------------|
| Decker Lake         | 44.069 | -114.889 | y      | 6.250           |
| Martha Lake         | 44.287 | -115.095 | y      | 3.000           |
| Sawtooth City       | 43.894 | -114.838 | y      | 0.700           |
| Hellroaring Moraine | 44.032 | -114.862 | y      | 1.740           |
| Goat Meadow         | 44.195 | -114.987 | y      | 1.180           |
| Marshall Lake       | 44.159 | -114.985 | y      | 2.840           |
| Hidden Lake         | 44.296 | -115.115 | y      | 5.370           |
| Decker Lake 2       | 44.041 | -114.892 | y      | 0.960           |
| Cabin Creek 1       | 43.917 | -114.906 | y      | 8.600           |
| Cabin Creek 2       | 43.921 | -114.907 | y      | 5.600           |
| Running Cow Pond    | 43.929 | -114.894 | y      | 2.250           |
| Big Bench           | 44.116 | -114.959 | y      | 5.740           |
| Lil Bench           | 44.146 | -114.951 | y      | 5.270           |
| Fishhook Pond       | 44.143 | -114.959 | y      | 1.500           |
| Dutch Lake          | 44.345 | -115.166 | y      | 3.250           |
| Cape Horn           | 44.413 | -115.131 | y      | 4.71            |
| Cape Horn II        | 44.404 | -115.136 | y      | 4.16            |
| Elk Lake            | 44.413 | -115.038 | y      | 4               |
| KES Lake            | 44.373 | -115.038 | y      | 4.5             |
| F-82                | 44.398 | -115.074 | y      | 3.77            |
| Bayhorse            | 44.412 | -114.402 | y      | 6.69            |
| Bull Trout Lake     | 44.300 | -115.253 | n      | na              |
| Martin Lake         | 44.303 | -115.263 | n      | na              |
| Ankle Roll          | 44.146 | -114.986 | n      | na              |
| Heart Lake          | 44.029 | -114.677 | n      | na              |
| Six Lakes 1         | 44.025 | -114.676 | n      | na              |
| Six Lakes 2         | 44.025 | -114.672 | n      | na              |
| Six Lakes 3         | 44.020 | -114.671 | n      | na              |
| Phyllis Lake        | 44.023 | -114.647 | n      | na              |
| Arrastra            | 44.850 | -114.360 | n      | na              |
| Unnamed 1           | 44.291 | -115.278 | n      | na              |
| Unnamed 2           | 44.308 | -115.251 | n      | na              |
| Unnamed 3           | 44.312 | -115.246 | n      | na              |
| Unnamed 4           | 44.304 | -115.257 | n      | na              |
| Unnamed 5           | 44.304 | -115.257 | n      | na              |
| Unnamed 6           | 44.344 | -115.167 | n      | na              |
| Unnamed 7           | 44.345 | -115.165 | n      | na              |
| Unnamed 8           | 44.347 | -115.167 | n      | na              |
| Unnamed 9           | 44.320 | -115.105 | n      | na              |
| Unnamed 10          | 44.303 | -115.114 | n      | na              |
| Unnamed 11          | 44.279 | -115.113 | n      | na              |
| Unnamed 12          | 44.193 | -114.998 | n      | na              |
| Unnamed 13          | 44.198 | -115.004 | n      | na              |
| Unnamed 14          | 44.209 | -115.007 | n      | na              |

| <b>Name</b> | <b>Lat</b> | <b>Long</b> | <b>Cored?</b> | <b>Water Depth (m)</b> |
|-------------|------------|-------------|---------------|------------------------|
| Unnamed 16  | 43.932     | -114.901    | n             | na                     |
| Unnamed 17  | 43.930     | -114.904    | n             | na                     |
| Unnamed 18  | 43.926     | -114.900    | n             | na                     |
| Unnamed 19  | 43.929     | -114.893    | n             | na                     |
| Unnamed 20  | 43.929     | -114.891    | n             | na                     |
| Unnamed 21  | 43.929     | -114.890    | n             | na                     |