uOttawa

L'Université canadienne
Canada's university

FACULTÉ DES ÉTUDES SUPÉRIEURES ET POSTOCTORALES

uOttawa

L'Université canadienne
Canada's university

FACULTY OF GRADUATE AND POSDOCTORAL STUDIES

Rebecca Ravindra
AUTEUR DE LA THÈSE / AUTHOR OF THESIS

M.Sc. (Geography)
GRADE / DEGREE

Faculty of Geography
FACULTÉ, ÉCOLE, DÉPARTEMENT / FACULTY, SCHOOL, DEPARTMENT

A High-Resolution Vegetation, Fire, and Climate History from the Aishihik Region, Yukon Territory, Canada

TITRE DE LA THÈSE / TITLE OF THESIS

Konrad Gajewski
DIRECTEUR (DIRECTRICE) DE LA THÈSE / THESIS SUPERVISOR

CO-DIRECTEUR (CO-DIRECTRICE) DE LA THÈSE / THESIS CO-SUPERVISOR

EXAMINATEURS (EXAMINATRICES) DE LA THÈSE / THESIS EXAMINERS

Mike Sawada

Luke Copland

Matthew Peros

Gary W. Slater
Le Doyen de la Faculté des études supérieures et postdoctorales / Dean of the Faculty of Graduate and Postdoctoral Studies

A high-resolution vegetation, fire, and climate history from the Aishihik Region, Yukon Territory, Canada

Rebecca Ravindra

THESIS SUBMITTED TO THE
FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE MSc IN THE DEPARTMENT OF GEOGRAPHY

Department of Geography
Faculty of Arts
University of Ottawa

November 2009

Your file Votre référence
ISBN: 978-0-494-61149-4
Our file Notre référence
ISBN: 978-0-494-61149-4

Abstract

Paleocological studies based on the analysis of lake sediments offer the potential for high resolution and well-dated records of past environmental conditions. A 2.7 m sediment core raised from Lake WA01 (unofficial name, 61°14'41"N, 136°55'35"W, 1000 m.a.s.l.) in the Aishihik region of the southwest Yukon Territory documents the post-glacial vegetation, fire, and climate history of the region surrounding the study site. The earliest portion of the WA01 pollen record was characterized by the establishment of open birch-shrub tundra at the study site. *Picea glauca* then established ca. 9,900 cal yrs BP, and has since remained dominant on the landscape Progressively decreasing precipitation in the region over the last ca. 9,000 years, noted in a previous study by Viau *et al.* (2008), is not captured in the Lake WA01 climate reconstructions. From ca. 9,900 cal yrs BP to the present day, reconstructed mean July temperatures and total annual precipitation at the study site remained essentially constant. A short period of low total annual precipitation is noted from deglaciation at 10,500 cal yrs BP to 9,900 cal yrs BP. The regional-scale fire regime surrounding the study site increased gradually in intensity over the course of the Holocene. Local fires in the area immediately surrounding the study lake decreased gradually in frequency and/or size over the course of the Holocene, though the exact cause remains unclear. An alternating pattern in the sediment loss-on-ignition from Lake WA01 is related to similar trends in □^{18}O values from the Mount Logan oxygen isotope record (Fisher *et al.*, 2008). Based on a positive association between sediment carbonate content and enriched □^{18}O values from the Mount Logan record, it is proposed that periods of increased and decreased sediment carbonate content in the WA01 core are indicative of wetter and drier conditions at the study site, respectively.

Résumé

Les études paléoécologiques basées sur l'analyse des sédiments lacustres offrent la possibilité d'obtenir des chronologies de conditions paléoénvironmentaless à haute résolution avec une datation précise. Une carotte de sédiments prélevée du Lac WA01 (nom non officiel, 61°14'41"N, 136°55'35"W, 1000 m d'altitude) a enregistré des changements dans la végétation, le feu, et le climat de la région entourant le site d'étude durant l'Holocene. La plus ancienne partie de la séquence est caractérisée par l'établissement d'un ouvert toundra arbustive à bouleau. *Picea glauca* ensuite a établi vers 9,900 ans BP, et la forêt d'épinettes blanches, ressemblante à celle de l'époque moderne, a été établie dans la région à aujourd'hui. De 9,900 ans BP à aujourd'hui, les températures moyennes du mois de juillet, puis la précipitation totale annuelle sont également restées pratiquement constantes; une diminution de la précipitation est observée à partir du tardiglaciaire à 9,900 ans BP. Le régime régional de feu autour du site d'étude a augmenté graduellement en intensité au cours de l'Holocène, et est interprété comme étant à la suite d'une diminution progressive de la précipitation de la région au cours du dernier 9,000 ans, noté dans une étude précédente par Viau *et al.* (2008). Les feux locaux dans la zone entourant le lac d'étude ont diminué progressivement en fréquence et/ou en la taille au cours de l'Holocène, quoique la cause exacte est incertaine. Une tendance notoire entre les produits biologiques et les carbonates est liée à des tendances similaires dans les valeurs de □ ^{18}O à partir des données isotopiques de l'oxygène du mont Logan (Fisher *et al.*, 2008). Il est proposé que l'association positive entre les carbonates et les valeurs □ ^{18}O enrichies constituent des périodes plus humides et des conditions plus sèches ont le site d'étude.

Acknowledgements

There are many who deserve my profound gratitude for the role that they have played in bringing this project to completion. First and foremost, I would like to thank my supervisor, Dr. Konrad Gajewski, for his continual help and support. The dedication and energy that he brings to his work drives his students to place more effort into their own projects, to their great benefit. This venture has become what it is because of his guidance and encouragement. I cannot thank him enough for all that he has done for me and for the many other students he has taught over the years.

I would also like to thank my thesis committee, Drs. Luke Copland and Mike Sawada, for their help, support and constructive comments, which have fine-tuned this work so that it is something that I can be truly proud of. I am greatly indebted to them for their wise council and advice.

Thank you also to the National Sciences and Engineering Research Council and to the Northern Scientific Training Program for providing me with the financial support that has allowed to me to focus on my research, and to conduct the fieldwork around which this project is based. Thank you also to the Arctic Institute of North America and to Andy and Carol Williams, Sian Williams and Lance Goodwin for logistical support in the field and for making the research base in Kluane my home away from home. Thank you to Dr. Matthew Peros, and to Phil Mosher, Sarah Boteler and Joey Taylor for help in the field and for their enduring enthusiasm on what was undoubtedly a very long day. Thank you also to Dr. Luke Copland for lending me his students, even when they probably had other things that they should have been doing.

Thank you to all of the members of the LPC and to the staff of the Department of Geography, who generously offered their time to help me to resolve any problems that I have encountered along the way. Completing this piece of research would have been made much more difficult without the benefit of their knowledge and experience.

I would like to gratefully acknowledge Dr. Peter Johnson for introducing me to field work in Geography. The work that he has done and continues to do has touched the lives of more students than I think he is aware of. I am truly grateful for all of the help that he has offered for the years that I have known him, and I hope that he feels I have justified all of the faith that he has placed in me. My deepest thanks are also given to my family and friends for their support and patience over not only the last two years, but also the many years that came before that.

Finally, I owe my greatest debt to my partner, Luc, for his support, patience and love as I have worked to complete this degree, and as I move on to my next one. None of what I have accomplished now would have been possible without his presence in my life.

R.R.
Ottawa, ON
September, 2009

Table of Contents

List of Tables

List of Figures

Chapter 1 – Introduction and Regional setting

1.1 Introduction

The study of recent climate warming in the Canadian North has been at the forefront of much scientific research in the natural sciences. Over the course of the 20th century, the northern climate has shown significant warming, with some locations registering an increase in air temperatures of up to 5°C since the turn of the last century (IPCC, 2007). Climate models consistently predict "substantial" further increases in temperature during the 21st century, with potentially significant impacts on northern ecosystems. Potential impacts of climate change on the northern environment include alterations to the physical and chemical properties of lakes (Kalff, 2002; Overpeck *et al.*, 1997), to the position and nature of treeline (IPCC, 2007; Jacoby & D'Arrigo, 1995; Overpeck *et al.*, 1997), to the extent of permafrost and sea-ice (IPCC, 2007), to the species composition, diversity, and productivity of terrestrial environments (IPCC, 2007; Overpeck *et al.*, 1997), and to the frequency and intensity of rainfall (IPCC, 2007) and of disturbances such as fire and drought.

It is important to understand how modern climate change fits in to the larger context of global climate change over the history of the Earth. Due to the sequential accumulation of sediments in lake basins, lake sediment cores can provide long-term records of the environment (Smol, 2002). Historical proxy-climate records allow us to place the current warming into a larger temporal frame of reference. These records can often be used to produce quantitative reconstructions of climatic variables such as temperature and precipitation, and thus provide valuable insights into the nature of past ecosystems (Smol, 2002). Proxy-climate records can also provide insight into the effects that climatic change can have on the landscape.

Fossil pollen recovered from lake sediments and other depositional environments is a common proxy used to reconstruct the composition of past vegetation communities (Faegri & Iverson, 1989). Since the vegetation in a region is related to the climate, fossil pollen can also be used to generate quantitative reconstructions of various climate parameters (e.g. Sawada *et al.*, 2004; Viau *et al.*, 2006; Willard *et al.*, 2007; Minckley *et al.*, 2007; Zabenskie & Gajewski, 2007, Bunbury & Gajewski, 2009a). A number of pollen diagrams have been prepared in the region of interest to this study from sites across northwestern Canada and Alaska (e.g. Wang, 1989; Lacourse & Gajewski, 2000; Cwynar, 1982, 1988; Cwynar & Spear, 1991, 1995; Szeicz & MacDonald, 2001; Stuart *et al.*, 1989; Birks, 1980; Keenan & Cwynar, 1992; Bourgeois & Guerts, 1983; Rampton, 1971; Carlson & Finney, 2004; Ritchie, 1982; Pisaric *et al.*, 2001; Cwynar & Ritchie, 1980; Wang & Guerts 1991a, b; Bunbury & Gajewski, 2009a). The temporal resolution of many of these studies is often quite low, however, due in part to the long time that they take to complete. The spatial density of paleoenvironmental records is also low in many parts of the Canadian North and Northwest, necessitating further study.

It is unclear how future climate change will impact the frequency of disturbances such as fire and drought. Fire is the most important agent of disturbance in the boreal forest (MacDonald, 2003), and plays an important role in the renewal of the stand and the maintenance of diversity, for example by opening clearings in areas of mature conifers so that light is able to penetrate to the ground (Aber & Melillo, 2001). Fire also plays an important role in the cycling of nutrients by accelerating the breakdown of material. Indeed, fire is so important in the boreal forest that some species of conifer require fire in order to reproduce (e.g. serotinous cones; Aber & Melillo, 2001). In the light of recent climate change in the Canadian North, it is unclear whether boreal forest fires will become more or less frequent in the future. Fire also poses a danger to human settlements in the region and to the Northern economy, which depends on the boreal forest to, for example, provide fuel, or supply raw material to the pulp and paper industry. Thus, the possibility that changes to the frequency of fires will occur in the boreal forest in the future poses a question that is more than simply academic in scope. Similar to the role that pollen analysis plays in understanding vegetation and climate history, paleocharcoal studies can provide insights into the history and frequency of fires in a region by the quantification of charcoal particles preserved in lake sediments (Whitlock & Larson, 2001).

This thesis presents a high-resolution pollen diagram from the Aishihik region of the southwest Yukon Territory, Canada, derived from the analysis of pollen deposited in the sediment of a small lake. The results of microscopic and macroscopic charcoal analysis are also presented to provide a high-resolution fire history for the region. A statistical comparison of pollen assemblages from the core with modern data available from the North American Modern Pollen Database (Whitmore *et al.*, 2004) has also been used to derive temperature and precipitation reconstructions down-core for the period covered by the sediment record. These inferred climate records are then related to independent records of climate from ice cores in the region (e.g. Mount Logan ice core).

The thesis is organized into five chapters. After the first introductory chapter, a second chapter provides a brief review of pollen and charcoal-based paleoecological research. Chapter 3 outlines in detail the methodology used. Chapter 4 is written in article format and is the focal point of the thesis. Chapter 5 is a summary of the thesis findings and suggestions for future work.

1.2 Regional setting

Lake WA01 (unofficial name; 61°14'41"N, 136°55'35"W, 1000 m.a.s.l.) is located between the Ruby Range and Klondike Plateau in the Aishihik region of the southwest Yukon Territory (Figure 1.1). Lake WA01 is a small closed-basin lake with an area less than 0.1 ha and a maximum depth during the summer of 2008 of approximately 1 m. Evidence of previous shorelines was clearly visible around the lake at the time of coring, suggesting that at one time the lake may have been significantly larger and deeper than it was at the time the core was collected (Figure 1.2). Similar marks of previous shorelines are found around many lakes in the area. A pH of 8.22 and water conductivity of 284 μScm^{-1} was measured on the date of coring on July 17th, 2008.

The area surrounding the study lake is underlain by Precambrian-Paleozoic sedimentary bedrock of the Cordilleran orogen, and is in a region of extensive discontinuous permafrost (50-90%). Surface material is comprised of till blankets (Fulton, 1995). Mean annual temperature in the study area is below 0°C, and precipitation is below 300 mm per year, resulting in a cold, semi-arid climate (National Atlas Information Service, 1995; Table 1.1). The region has a variable topography characterized by high ridges and hills surrounding numerous low-lying depressions. The study lake itself is located in a small depression surrounded by steep forested slopes on all sides. Many other small lakes are also located in the region, in depressions surrounded by steep slopes.

The vegetation surrounding the study site is characterized by the presence of low-density boreal forests dominated by white spruce (*Picea glauca*). White spruce stands in the region tend to be found on well-drained soils and on the sides and tops of slopes. Stands of poplar and aspen (*Populus*) as well as birch (*Betula*) and alder (*Alnus*) are also common, particularly in low-lying areas and on more poorly drained sites (Wang, 1989). In the understory, the vegetation includes juniper (*Juniperus*) and willow (*Salix*) as well as numerous herbaceous plants such as species of grasses (Poaceae) and sedges (Cyperaceae), which tend to occur on more poorly drained sites. *Epilobium* and *Shepherdia* also form a small component of the modern vegetation, and are principally found on well-drained soils.

Between 1960 and 2000 AD, 205 fires burned in the region around the study lake, over an area of 195 km^2 (McCoy & Burn, 2005). Lightning strikes accounted for 5.9% of these. Seventy percent of the fires that occur each year burn during the months of June, July, and August.

Chapter 2 – Literature review

2.1 Paleolimnology

A number of different paleoenvironmental indicators are capable of being preserved in lakes as sediments accumulate through time. These include allochtonous (produced outside of the lake) pollen grains, spores, charcoal, and other remains, and autochtonous (produced within the lake) pollen, diatoms, chironomid head capsules, and algal pigments (Smol, 2002). It is also possible to use sediment parameters such as magnetic susceptibility and loss-on-ignition to interpret the nature of past sedimentary environments (Smol, 2002).

In paleolimnological studies, cores of sediment are collected from the bottom of lake basins. The selection of the lake to be cored is done very carefully, as variations in lake morphometry can redistribute sediment in ways that can sometimes complicate analysis, and it is best if this can be avoided (Smol, 2002). Ideally, a lake will have a deep and flat central area from which the sediment core can be collected. However, the physical, biological, and chemical traits of the lake must also, of course, be appropriate to the question under study, as must the location of the core within the lake (Smol, 2002).

Once the core is collected, it is necessary to establish an age-depth profile for the core so that changes in the characteristics of the core and/or its incorporated paleoenvironmental indicators can be related to particular times in history. There are a number of ways in which an age-depth sequence can be developed, including incremental dating (using varves), anthropogenic markers, and radio-isotopic techniques (Smol, 2002). By far the most common and useful dating method for sediments is the use of radio-isotopic methods such as those that employ ^{210}Pb and ^{14}C to establish dates for different levels in the sediment. Fossil indicator data is then collected and analyzed to answer questions relating to the nature of the past environment surrounding or within the study lake.

2.2 Pollen analysis

2.2.1 Biology and transport

Pollen grains are a reproductive structure (the male gametophyte) of plants produced in the anthers of angiosperms and gymnosperms. The pollen grain is composed of a male nucleus (sperm; used for fertilization of an egg) surrounded by a wall made of cellulose and a substance called sporopollenin. Sporopollenin is extremely resistant to many forms of chemical and physical degradation except oxidation, allowing the outer wall of pollen grains to be preserved for long periods in anaerobic environments, such as lake sediments (Bennett & Willis, 2001). In addition, the outer surface of the pollen grain is often sculpted or patterned in a way characteristic of a certain taxon. This trait allows pollen grains to be identified to various taxonomic levels and forms the basis for pollen analysis (Bennett & Willis, 2001). Other vascular plants (e.g. ferns and club mosses) as well as some mosses produce spores that can also be identified in pollen analysis.

Pollen grains are transported from plant to plant in a number of ways, including by animals (zoophily), insects (entomophily), and wind (anemophily). Zoophilous and entomophilous plants tend to produce fewer and larger pollen grains than anemophilous species, and therefore it is rare to find pollen grains of these types in sediments. Anemophilous pollen grains are typically produced in large quantities and are generally quite small (though there are some notable exceptions, e.g. *Pinus* and *Picea*, whose pollen grains are quite large). These pollen grains are released to the air by the parent plant and are mixed in the atmosphere by the wind until they are deposited as the "pollen rain" (Faegri & Iverson, 1989). Most of these grains will, however, not pollinate another plant of the same species, but will fall out of the air and be lost. The portion of these lost grains that is deposited into lake environments is preserved and can be recovered and studied in pollen analysis. Pollen grains deposited to other sedimentary environments (such as bogs) can also sometimes be recovered and studied in a similar way.

2.2.2 Deposition and pollen source area

Faegri & Iverson (1989) divide the pollen rain to a lake (or other environment) into three components. The first is the gravity component, or the portion of the pollen rain deposited to the lake that has fallen straight down into the sediments, or which has been transported very short distances from the parent plant. The second component is the local component, or the pollen that has been transported more or less in contact with the upper surface of the local vegetation. This pollen is also generally transported only a very short way before it is deposited. The final and most important component of the pollen rain is the regional component. This component of the pollen rain is transported high above the vegetation and for longer distances than the gravity or local components. It is this component that contributes the majority of the pollen grains that are deposited to lake sediments. The pollen that is preserved in lake sediments is therefore representative of the regional vegetation (Birks & Birks, 1980). Through pollen analysis, it is possible to reconstruct the composition of the vegetation that surrounded a site through history, and how it has changed. Pollen records can then be used to describe the nature of the regional climate at different points in time, due to the close relationship that typically exists between vegetation composition and regional climatic conditions.

2.2.3 Pollen preservation and recovery

Because of the resistant properties of sporopollenin, the exines (walls) of pollen grains are preserved in lake sediments long after they have been deposited. The condition of the grain, however, can vary from being well preserved to being so badly degraded as to make it unidentifiable. Grains whose exines have high sporopollenin content (e.g. *Pinus*) are better preserved than those whose exines have lower amounts of sporopollenin incorporated into the wall of the grain (e.g. *Populus*; Birks & Birks, 1980). In general, however, pollen grains are well preserved in lake sediments and thus have been used extensively to reconstruct past environments.

The practice of pollen analysis requires that the pollen that is preserved in sediments be recovered, isolated, and identified. Lake sediment cores can be collected using a variety of tools and coring techniques (Smol, 2002). Since pollen grains are very small (5-100 μm), many hundreds may be contained in small amounts of sediment. This allows good approximations of the composition of the parent vegetation community to be made without the need to sample and process huge amounts of sediment (Birks & Birks, 1980). The pollen in the core can then be isolated by digestion of the sediments with a sequence of harsh chemicals. The resistant cell walls of the pollen grains withstand the effects of these chemicals and are thus left in the residue following the isolation process. These remnants are then mounted on slides and examined under high magnification. The characteristic structure, sculpture, and patterning on the surface of the exines of different pollen taxa allow their identification through comparison of fossil grains with modern grains of known origin. It is important to note that digestion of the non-polleniferous material in the sediment is typically incomplete, so the material remaining on a slide contains not only pollen grains, but also a considerable amount of other matter, including microcharcoal particles.

2.2.4 Pollen analysis

The results of pollen analysis are typically presented as a pollen diagram showing the contribution of each taxon to the total number of grains that have been counted at various levels in the core. The contribution of each taxon is presented as a percentage of the pollen sum at each level and the diagram is often zoned into sections of time representing similar assemblages of pollen. These zones can be defined by visual inspection or by the application of computer techniques such as ordination or cluster analysis. Other notable characteristics or transitions in the core (e.g. in sediment parameters) can also sometimes be used to guide the interpretation of sediment records and can greatly aid in the interpretation of past environments.

Pollen percentage diagrams provide excellent summaries of the composition of, and changes in, the regional vegetation surrounding a site through time. Information relating to the absolute quantity of pollen being deposited to the lake over time, however, is lost due to the percentage computation. An alternative to the presentation of pollen percentages is to compute the pollen influx, which presents pollen data as the number of grains of different taxa being deposited to the sediment each year. This then provides some indication of the productivity of the vegetation through time, as well as of the taxonomic composition of the community (Hicks & Hyvarinen, 1999; Gajewski, 1995). The calculation of pollen influx requires pollen concentrations and sediment accumulation rates at each level of the sediment to be known. This can complicate the interpretation of pollen influx information, as the sediments must be extremely well dated in order to allow confident estimation of sedimentation rates through time. These complications have kept pollen influx from being considered in many pollen studies, though when carefully interpreted, the use of pollen influx can provide significant and valuable additional information.

2.2.5 Pollen analysis in western Canada and Alaska

Wang (1989) summarizes post-glacial vegetation succession at nine sites in the northern and southwestern Aishihik region. Immediately after glaciation, the study area was dominated by sparse herb tundra. At 10,000 ^{14}C yrs BP, the percentage of *Betula* pollen increased, indicating the establishment of birch shrub-tundra in the region, which has also been reported by Lacourse & Gajewski (2000), among others. White spruce (*Picea glauca*) pollen is noted at ca. 9,000 ^{14}C yrs BP in the upper Nisling Valley and Ittlemit Lake Basin, and at 8,600 ^{14}C yrs BP in the southwestern Aishihik Basin. The author suggests that alder (*Alnus* spp.) has never been common in the Aishihik region, as it has been at sites farther to the north. This is interpreted as being the result of the dry semi-arid climate of the Aishihik Basin (Wang, 1989).

In a pollen study from Sulphur Lake in the southwest Yukon, Lacourse & Gajewski (2000) identified 5 pollen zones in an approximately 12,000-year record. Sediments older than 11,250 ^{14}C yrs BP were characterized by a *Betula-Artemisia-Salix*-Cyperaceae assemblage, suggestive of an herbaceous tundra environment. From 11,250 to 10,250 ^{14}C yrs BP, the percentage of *Betula* pollen increased significantly; the authors conclude that this represents the establishment of a birch shrub-tundra at the site. Between 10,250 and 8,400 ^{14}C yrs BP, *Betula* was gradually replaced by increasing percentages of *Populus* pollen. *Juniperus* also established on the landscape during this time, probably in gaps in the forest canopy (Lacourse & Gajewski, 2000). Zone 4 (8,400-6,000 ^{14}C yrs BP) was characterized by the arrival of white spruce (*Picea glauca*). Finally, Zone 5 (6,000 ^{14}C yrs BP-present) is identified on the basis of continued dominance of *Picea glauca* pollen, as well as an increase in the percentage representation of *Alnus* pollen in the sediments, representing the final transition of the forest to modern conditions. Cwynar & Spear (1995) identified a similar rise in *Alnus* pollen at 6,000 ^{14}C yrs BP. Lacourse & Gajewski (2000) associate the establishment of *Alnus* with a transition to cooler and wetter conditions in the region.

Bunbury & Gajewki (2009a) identify a period of herbaceous tundra prior to ca. 12,500 cal yrs BP at Upper Fly Lake in the southwest Yukon. *Artemisia* increased between 12,500 and 11,200 cal yrs BP, corresponding to the timing of the Younger Dryas. Non-arboreal pollen types remained dominant at the site until ca. 10,000 cal yrs BP when *Picea glauca* increased in the assemblage and became dominant. This is interpreted as being indicative of the establishment of spruce forest in the region surrounding the study site at this time. Little change in the composition of the pollen assemblage is noted from the first establishment of *Picea glauca* to the present day, suggesting that the forest has not undergone and significant changes from 10,000 cal yrs BP to the present.

In a pollen study of Kettlehole Pond, YT, Cwynar (1988) identified 5 pollen zones similar to those identified by Lacourse & Gajewski (2000), with some notable exceptions. Cwynar's (1988) Zone 1 (11,030-9,250 ^{14}C yrs BP) is dominated primarily by *Populus* woodland and *Artemisia* dominated open areas. This corresponds most closely with Lacourse & Gajewski's (2000) Zone 3. Zone 2 (9,250-6,100 ^{14}C yrs BP) is characterized by the establishment of *Juniperus* on the landscape, and by increases in the percentage representation of *Picea glauca* pollen. From 6,100-4,100 ^{14}C yrs BP, Zone 3 is identified by increases in *Picea mariana* and *Alnus* pollen in the sediments. The author suggests that this indicates the establishment of wetter conditions in the study region during this time. Cwynar & Spear (1995) also noted an increase in *Picea mariana* pollen associated with increases in *Alnus* pollen percentages during this time period. Zone 4 (4,100-1,900 ^{14}C yrs BP) is characterized by the presence of *Abies*, as well as increases in *Juniperus* and *Selaginella* pollen, indicating the presence of more open forest cover. Finally, Zone 5 (1,900 ^{14}C yrs BP-present) is identified by the establishment of *Pinus contortata* on the landscape, while *Picea mariana* pollen disappears entirely from the pollen rain.

Cwynar & Spear (1991) summarize the vegetation history at Grayday, Honeymoon, and Monkshood Ponds in the central Yukon. As found by Lacourse & Gajewski (2000) and Cwynar (1988), the time from 10,000-8,000 ^{14}C yrs BP was characterized by the establishment of *Populus* on the landscape, likely in groves. *Picea glauca* established at 9,400 ^{14}C yrs BP at these sites, and persisted until 6,500 ^{14}C yrs BP when *P. mariana* and *Alnus* pollen began to increase. At 5,000 ^{14}C yrs BP, the vegetation began to return to its previous shrub tundra composition (Cwynar & Spear, 1991).

Additional pollen diagrams for the Yukon-Alaska region have been presented by Szeicz & MacDonald (2001), Birks (1980), Bourgeois & Guerts (1983), Carlson & Finney (2004), Pisaric (2001) Ritchie (1982), Cwynar (1982), and Cwynar & Ritchie (1980), among others. Despite the extensive body of work from the region, however, questions persist related to the manner and timing of the post-glacial migration of spruce into the southwest Yukon. Cwynar & Spear (1991) comment on the ambiguity of the manner and timing of spruce migration into the Yukon since the end of the Wisconsin. Bunbury and Gajewski (2009a) have placed the regional-scale establishment of *Picea glauca* at ca. 10,000 cal yrs BP at Upper Fly Lake. Studies of Grayday, Honeymoon, and Monkshood Ponds in the central Yukon indicate that white spruce (*Picea glauca*) was present in the central parts of the Territory by 9,400 ^{14}C yrs BP (Cwynar & Spear, 1991). The presence of white spruce has also been identified at 9,000 ^{14}C yrs BP in the upper Nisling Valley and

Ittlemit Lake Basin, and at 8,600 ^{14}C yrs BP in the southwestern Aishihik Basin (Wang, 1989). Lacourse & Gajewski (2000) have interpreted spruce establishment at Sulphur Lake in the southwest Yukon at 8,400 ^{14}C yrs BP; a similar date has been suggested by Stuart *et al.* (1989) at nearby Jenny Lake, where the timing of spruce establishment has been placed at 8,500 ^{14}C yrs BP. Lastly, Cwynar (1988) suggests that spruce established at Kettlehole Pond by 9,250 ^{14}C yrs BP, and Rampton (1971) has identified spruce establishment at Antifreeze Pond, at the Yukon-Alaska border at 8,700 ^{14}C yrs BP. Thus, the precise timing of spruce migration into the southwest Yukon remains a question of significant interest and debate.

The route of spruce migration into the area of the southwest Yukon is as yet also unclear. Colinvaux (1964), Brubaker *et al.* (2005), and Anderson *et al.* (2006a), among others have suggested that spruce migrated into the study region and the remainder of northern North America from eastern Beringian refugia soon after the end of the last glaciation. Another alternate possible migration route has been suggested by Cwynar (1982, 1988), who proposed that spruce migrated north from British Columbia through the Liard and Yukon River systems and then continued northwestward into the southwest Yukon. Lacourse and Gajewski (2000) suggest that spruce may have migrated from northern British Columbia to the Liard River and from there into the Tintina Trench. From the Tintina Trench, the authors then suggest that spruce could conceivably have migrated south and westward into the Aishihik Basin and then into the Shakwak Trench (Lacourse & Gajewski, 2000). Further study is thus required to develop our understanding of the route of post-glacial spruce migration into the southwest Yukon.

2.2.6 Climate reconstructions

The vegetation in a region is related to the climate (Birks & Birks, 1980). Thus, by identifying the pollen that has been trapped and preserved in lake sediments over time, we are capable of reconstructing past climates either qualitatively by interpreting the pollen assemblage to reconstruct the past vegetation and then using that information to infer climate conditions, or quantitatively if appropriate calibration data are available. By the application of the Modern Analogue Technique (MAT), for example, in which fossil pollen assemblages determined through pollen analysis are compared to modern pollen spectra from across a geographical and climatic gradient, quantitative reconstructions of a variety of climatic variables through time are possible. A large database of modern pollen spectra comprised of over 4,000 samples from across North America, and including 134 different pollen taxa, is available for the application of the MAT (Whitmore *et al.*, 2005). This dataset has been successfully applied to reconstruct climate change during the Holocene and late Wisconsin in a number of recent studies (e.g. Sawada *et al.*, 2004; Viau *et al.*, 2006; Willard *et al.*, 2007; Minckley *et al.*, 2007; Zabenskie & Gajewski, 2007; Bunbury & Gajewski, 2009a), and is used here to reconstruct mean July temperature and mean annual precipitation through time for the study lake.

2.3 Charcoal analysis

2.3.1 Role of fire in the boreal forest

Fire is the most important agent of disturbance in the boreal forest (MacDonald, 2003), however, the frequency of forest fires in the boreal forest of North America varies considerably, from 20 years in the dry interior to thousands of years at treeline

(MacDonald, 2003). In the boreal forest of northwestern Canada and Alaska, fire burns through the forest every 80 to 400 years, on average. Lightning typically starts most natural (i.e. non-anthropogenically started) fires in this region (MacDonald, 2003).

Coniferous trees such as pine (*Pinus*) and spruce (*Picea*) often contain large quantities of volatile oils and resins that make them highly flammable. In addition, many species of conifer have dead lower branches that act as fire ladders, which allow fire to move into the canopy. A number of boreal forest tree species exhibit adaptations to fire such as thick bark or the ability to re-sprout after a fire (called epicormic sprouting; MacDonald, 2003). Serotinous cones are also common. The scales of serotinous cones remain closed by a resin until heated by a fire. Upon heating, the resin melts and the cones open and release their seeds. The seeds can remain viable within the cone for up to 75 years in some cases (MacDonald, 2003). By burning away deadwood and litter, fire also releases nutrients to the soil and creates openings in the canopy where shade-intolerant herbaceous plants and tree seedlings can establish. Herbaceous vegetation is also an important food source for animals. Fire is thus a necessary part of the life cycle of the boreal forest.

The typical successional sequence of the boreal forest has been studied using chronosequence (e.g. Yarie, 1983; Cogbill, 1985; Zoladeski & Maycock, 1990), stand reconstruction (Galipeau *et al.*, 1997; Sirois & Payette, 1989), and direct observational (Johnstone *et al.*, 2004) techniques. MacDonald (2003) and Aber & Melillo (2001) summarize the typical successional sequence of *Picea glauca*-dominated boreal forest stands in northwestern Canada and Alaska. Immediately after the fire, the shading effect of the previous conifer canopy is removed, and sunlight is able to penetrate to the forest floor. Ash provides nutrients to the soil. The depth of the permafrost decreases and encourages the mineralization of organic matter, further increasing the amount of available nutrients. In the two to five years immediately after a fire, the site is usually dominated by species of grass (Poaceae), and herbs such as fireweed (*Epilobium*) and willow (*Salix*). The seedlings of deciduous and coniferous trees also establish at this time. For the next 25 years, the site is dominated by willow and birch (*Betula*) shrubs. Aspen (*Populus*) and sometimes paper birch (*Betula papyrifera*) saplings gradually mature during this time, and deciduous trees dominate the site for the next 50 years. After about 100 years, *Picea* once again dominates the system. A thick moss layer develops on the ground beneath the trees after about 200 years. The active layer decreases through time. At this point there are few deciduous trees still growing within the forest, and the system is thus dominated by coniferous species.

2.3.2 Charcoal production, transport, and deposition

Charcoal is produced when fire does not completely consume organic material, generally at temperatures between 280 and 500°C (MacDonald *et al.*, 1991). Charcoal particles recovered from lake sediments and other sedimentary environments are generally divided into two major classes based on their size. As with pollen, microscopic particles of charcoal (<125 µm) are transported long distances by the wind, and so are representative of regional-scale patterns of fire (tens of km). These particles are eventually deposited onto the landscape, and some of these then become trapped in lake sediments and are preserved. Microcharcoal records from lake sediments are thus capable of providing insights into regional fire histories (Whitlock & Larsen, 2001).

It is also possible to study and quantify macroscopic charcoal (>125 µm) as a proxy for local fires (Whitlock & Larsen, 2001). These large particles of charcoal are not carried for long distances by the wind, and thus are deposited much closer to their source than is microscopic charcoal. Most macroscopic particles of charcoal are deposited within 60 m of the edge of the fire (Lynch *et al.*, 2003). When used in combination with microcharcoal analysis, studies of macroscopic charcoal are often used in order to determine whether peaks in the microscopic charcoal record represent regional fires that also burned locally around the lake (Whitlock & Larsen, 2001).

2.3.3 Charcoal identification in lake sediments

Because particles of microscopic charcoal are mixed and transported by the wind before they are deposited, their source area is considered to be similar to that of pollen (Whitlock & Larsen, 2001). In addition, microscopic charcoal particles are often retained on pollen slides that have been prepared using standard techniques. Once mounted onto slides, microscopic charcoal particles are counted or measured similarly to pollen grains. The amount of charcoal on a slide is then expressed as an accumulation rate (Whitlock & Larsen, 2001).

Because pollen studies are so labor-intensive and require such long time-periods to complete, sampling intervals in cores are often quite widely spaced. In cases where microscopic charcoal is also quantified, this provides an incomplete record of fires in the region, where long time periods (and perhaps major fire periods) are not included in the analysis. For this reason, in microscopic charcoal analysis, it is often not possible to generate estimates of local fire recurrence, and studies that undertake to develop fire histories often do so using macroscopic charcoal (Whitlock & Larsen, 2001).

Macrocharcoal analyses are typically performed continuously in sediment cores and thus allow the development of detailed local fire histories. Macrocharcoal records record the occurrence of local fires, and thus can at times allow the nature of local post-fire succession to be examined in detail when macrocharcoal analyses are combined with pollen studies of sufficiently high resolution (Whitlock & Larsen, 2001). Because macrocharcoal only records the occurrence of local fires, however, large networks of sites are required before a general idea of the fire regime in a wider area can be gained. The combination of high-resolution microcharcoal analysis with continuous macrocharcoal analysis thus provides the most complete fire record possible for a given study area.

Macrocharcoal that becomes trapped in lake sediments is further divided into two new categories, termed primary and secondary charcoal. Primary charcoal particles are deposited directly from a fire either during or soon after the event, whereas secondary charcoal is washed into the lake from the surrounding watershed gradually over many years. Secondary charcoal, then, provides a "background" level of charcoal that is constantly being inputted to the lake sediments. The input of primary charcoal from a fire will thus cause a spike in the macrocharcoal record (Whitlock & Larsen, 2001).

2.3.4 Fossil charcoal studies in western Canada and Alaska

There is only one lake charcoal-based fire history that has been produced for the Yukon Territory (Keyhole Pond, SW Yukon, 61°8'N, 137°37'W; Whittmire, 2000). Whittmire (2000) first identifies a period of low fire activity coincident with open steppe/tundra-type vegetation extending from deglaciation to ca. 10,400 ^{14}C yrs BP. From 10,400 to 8,200 ^{14}C yrs BP, fire activity increased coincident with the establishment of poplar (*Populus*) woodlands. By 8,200 ^{14}C yrs BP, *Picea glauca* was dominant at the site. Fire activity peaked ca. 5,820 ^{14}C yrs BP. This coincided with a decline in the amount of *Picea* pollen and an increase in shrub and grass species. The author notes that fire activity has been more variable over the last 1,500 years than previously, but makes no comment as to what may be the cause of this change in the fire regime (Whittmire, 2000).

While Whittmire (2000) remains the only lake charcoal-based fire record for the Yukon Territory, a number of records of forest fire activity in northwestern Canada and Alaska have been developed from ice cores taken in the St. Elias Mountains (Yalcin *et al.*

2006; Holdsworth *et al.*, 1996; Whitlow *et al.*, 1994). Three ice cores from the Eclipse Icefield record increased fire activity in Alaska and Yukon Territory during the 1760s, 1780s, 1840s, 1860s, 1880s, 1890s, 1920s-1940s, and 1980s AD through the analysis of NH_4^+ residuals carried in the ash plumes of past fires and deposited in the ice (Yalcin *et al.*, 2006). Whitlow *et al.* (2004) also found increased fire activity during the 1770s-1790s, 1810s-1830s, 1850s-1870s, and 1930s-1980s AD in an ice core taken from Mount Logan. Peak fire activity in the Eclipse record is recorded during the 1890s AD by Yalcin *et al.* (2006). This corresponds well to the results of Holdsworth *et al.* (1996), who found highest NH_4^+ concentrations between AD 1850 and 1910 in the Mount Logan ice core. Both Holdsworth *et al.* (1996) and Yalcin *et al.* (2006) interpret this as an increase in anthropogenic biomass burning near the turn of the 20th century. Low fire activity is recorded during the 1770s, 1810s-1830s, 1850s, 1950s, and 1960s AD in the Eclipse record (Yalcin *et al.*, 2006). A single long core from the Eclipse Icefield also records periods of high fire activity during the latter stages of the Medieval Warm Period (AD 1240-1410; Yalcin *et al.*, 2006).

Apart from Whittmire (2000), and the St. Elias records, a series of lake charcoal records that have been produced from sites in Alaska are the closest and likely most relevant records of fire history that are available for the region of this study. The majority of these base their analyses primarily on macrocharcoal.

At Paradox, Portage, and Arrow Lakes in Alaska, Anderson *et al.* (2006b) found that Mean Fire Intervals (MFIs) were highest from 13,000-10,700 cal yrs BP and from 4,600 cal yrs BP-present (MFI 138 +/-65 years and 130 +/-66 years, respectively) and lowest from 10,700-8,500 cal yrs BP (MFI 77 +/-49 years) and from 8,500-4,600 cal yrs BP

(81 +/-41 years). Time periods with the highest MFIs corresponded to vegetation communities dominated by *Betula kenaica-Salix-Populus* and *Picea glauca.*

Lynch *et al.* (2003) computed macrocharcoal-based MFIs for Rock, Portage, Arrow, Dune, and Deuce Lakes in the Kenai region and central Alaska. The authors found that in their study areas, the Charcoal Accumulation Rate (CHAR) had been low for the last 1,000 years except for a period of extremely high charcoal accumulation during the settlement of Alaska by the Europeans. During this time, CHARs increased to ten-times their previous values. Lynch *et al.* (2003) note low fire occurrence from 9,000-5,500 cal yrs BP, and an increase in fire frequency after 5,500 cal yrs BP. This occurs synchronously with the replacement of *Betula-P. mariana-Alnus* vegetation by *P. mariana* dominated communities.

At Grizzly and Lost Lakes in central Alaska, Tinner *et al.* (2006) found that fires were common ca. 13,200 cal yrs BP during the birch-shrub tundra phase of post-glacial succession. Fires in the study region were also common between 8,500 and 6,800 cal yrs BP and from 450-150 cal yrs BP. The MFI between 6,800 and 5,500 cal yrs BP was ~386 years. The MFI then decreased to ca. 254 years from 5,500 to 3,900 cal yrs BP, and to ca. 200 years from 3,900 cal yrs to the present. The analysis was based on the analysis of micro and macrocharcoal particles preserved in the lake sediments, and thus records the occurrence of both regional and local fires.

In south-central Alaska, Lynch *et al.* (2004) calculated an MFI of > 500 years before 3,800 cal yrs BP at Moose and Choksana Lakes, except from 5,800-5,000 cal yrs BP and from 5,400-4,550 cal yrs BP at the two sites, respectively (MFI ca. 200 years in each case). In the late Holocene, the MFI decreased to ca. 200 years at both of the sites, and decreased further to 150 years after 2,000 cal yrs BP. More fires appeared to occur in vegetation communities characterized by wetter conditions. The authors hypothesized that this could be due to an increase in the number of lightning strikes with more frequent rainfall events.

Hu *et al.* (1996) found that frequent fires occurred in the *Betula-Populus-Salix* dominated community that occurred at Farewell Lake in Alaska between 11,000 and 8,500 ^{14}C yrs BP. Fires were also frequent after ca. 6,000 ^{14}C yrs BP, when *P. mariana* became more prevalent on the landscape. In a review of general patterns of fire in Alaska, Hu *et al.* (2006) noted that increased fires tend to occur in *P. mariana* dominated forests, where MFIs can change from the average of ca. 300 years to around 80 years. *P. mariana* forests, however, are characterized by cooler and wetter conditions than characterize, for example, *P. glauca* forests. Hu *et al.* (2006) hypothesize that the increased fire frequency in *P. mariana* forests may be caused by the high flammability of this species in comparison to other taxa. They also acknowledge the possibility that increased lightning strikes might be an influence in causing increased number of fires. Lastly, Hu *et al.* (2006) note that the spatial distribution of fire regimes across Alaska through history appears to have been non-static; that is, sites that were in the past part of the same fire regime are not necessarily part of the same regime in the present day. The authors cite a number of both micro and macrocharcoal-based studies (e.g. microcharcoal – Tinner & Hu, 2001, 2003; macrocharcoal – Lynch *et al.*, 2003, 2004) as the justification for their conclusions. The dynamics of fire in the boreal forests of Alaska and northwestern Canada is thus still a subject of much interest to natural scientists working in the region.

2.4 Paleoclimate records

Lake sediment studies have provided an overview of environmental and climatic change stretching thousands of years into the past. A number of independent climate records are now available for correlation with sediment-based paleoenvironmental records derived from proxies such as pollen and charcoal. Isotopic records from Mount Logan, YT, for example, provide stable oxygen isotope ($\partial^{18}O$) records for northwest North America that span the Holocene (Fisher *et al.*, 2008), and which can be used to aid in the interpretation of lake sediment proxy records. Fisher *et al.* (2004) have suggested that changes to the enrichment/depletion of the $\partial^{18}O$ in the Mount Logan isotope record through time are related to periodic and sudden changes to the strength and position of the Aleutian Low (AL) in the North Pacific, as measured by the North Pacific Index (NPI). Anderson *et al.* (2005) suggest that when the AL is stronger or positioned further to the east, strong southerly winds lead to the enhancement of rainout on the coastal side of the Pacific Cordillera, and to the deposition of depleted $\partial^{18}O$ in the rain shadow on the other side. The authors associate these conditions with a drier climate in the interior (Anderson *et al.*, 2005). Conversely, when the AL is weaker or further west, the $\partial^{18}O$ flux is enriched and conditions are generally wetter on the lee side of the mountains.

Chapter 3 – Methods

3.1 Field Methods

A lake sediment core was collected from Lake WA01 (61°14'41"N, 136°55'35"W) on July 17th, 2008, using a 5 cm diameter, 1 m long Livingstone square-rod piston sampler (Wright, 1967), from a raft anchored at three points to the lake shore. The uppermost meter of sediments was collected using a plastic tube fitted with a piston to ensure that the sediment-water interface remained undisturbed. The uppermost unconsolidated sediments were extruded in the field into plastic bags at 0.5 cm intervals using a portable extruding device. The remaining sediment cores were extruded in the field, wrapped in plastic wrap and aluminum foil, and stored in split PVC tubing before being transported back to the field research station and then to the lab in Ottawa, Canada. The extruded cores and plastic bags of sediment were stored in a refrigerator at 4°C until analysis.

3.2 Laboratory methods

3.2.1 Sediment parameters

Magnetic susceptibility

Magnetic susceptibility is a non-destructive method of logging sediments that measures the ability of the sediment to be magnetized (Sandgren & Snowball, 2001). The sediments are subjected to a low-intensity magnetic field emitted by the sensor, and the degree of magnetization of the sediments is then computed. The results of the analysis can be used to correlate core segments, for example. In the southwest Yukon, magnetic susceptibility is used to identify volcanic tephra layers, even in cores where the layers are not visible. An increase in magnetic susceptibility may also indicate an increase in erosion from the lake's watershed (Lowe & Walker, 1997).

Whole core magnetic susceptibility of the WA01 core was measured using a Bartington MS2C Core Sensor with a 6 cm internal diameter. The analysis was conducted at 1 cm increments down the entire length of the core. The resulting data was used to match core segments and to identify the depth of the White River Ash (WRA; below) in the core.

Loss-on-ignition

Loss-on-ignition (LOI) is a method for estimating the proportion of organic and carbonate material found in lake sediments. The technique has been suggested by some as a potential method of estimating catchment productivity and possibly even paleoclimates, though the exact nature of how to interpret the data remains unclear (Birks & Birks, 2006). Studies by Levesque *et al.* (1994), Birks *et al.* (2000), Kaplan *et al.* (2002), Andresen *et al.* (2004), McKay *et al.* (2008), and Fortin & Gajewski (2009) have noted a positive relationship between the organic content of lake sediments and increased paleotemperatures interpreted from pollen and other proxy-climate indicators at sites in New Brunswick, Norway, Greenland, Alaska, and the Canadian Arctic. In these studies, the authors interpret increased sediment organic content in their cores as the result of warmer conditions around their study lakes, which caused increased catchment productivity, and thus an increase in organic material being deposited to the lake sediments. Brown *et al.* (2005) have also suggested that decreased organic material and increased carbonate material in the sediment can be interpreted as an indicator of wet conditions at their study site in the Canadian prairies.

Using a calibrated brass sampler, 0.5cc of sediment was sub-sampled from the WA01 core at continuous 1 cm intervals for loss-on-ignition analysis (Dean, 1974). The sediment samples were placed into crucibles of known weight for analysis. The wet weight of the sediment and crucibles was measured, prior to their being placed into a 105°C oven for 24 hours. Once dried, the samples were removed from the oven and allowed to return to room temperature within a dessicator; they were then weighed again to obtain the dry weight of the sediment (DW_{105}). The samples were next placed into a muffle furnace at 550°C for 4 hours, removed, returned to the dessicator to cool, and weighed to obtain the organic content (LOI_{550}). The samples were then again returned to the muffle furnace, this time at 950°C for 2 hours, removed, returned to the dessicator to cool, and weighed to obtain the carbonate content of the sediments (LOI_{950}; Dean, 1974; Heiri *et al.*, 2001). Loss-on-ignition was calculated as follows:

$$LOI_{550} = ((DW_{105} - DW_{550})/DW_{105}) * 100$$

$$LOI_{950} = ((DW_{550} - DW_{950}/DW_{105}) * 100$$

where LOI_{550} is related to the organic content of the sediments, LOI_{950} is related to carbonate content of the sediments, DW_{105} is the weight of the dried sample minus the weight of the crucible, DW_{550} is the weight of the sample after ignition at 550°C, and DW_{950} is the weight of the sample after ignition at 950°C (Heiri *et al.*, 2001).

3.2.2 Pollen analysis

Pollen preparation followed the protocol outlined by Faegri & Iverson (1989). Sediment was sub-sampled at 1-7 cm intervals along the core for analysis. Pre-acetolyzed *Lycopodium* tablets were added to the sediment samples prior to processing to allow the calculation of pollen and microcharcoal concentrations (Bennett & Willis, 2001). After the sub-sample was collected, and the *Lycopodium* spike was added, the sample was digested using 10% HCl to remove any carbonate material (Faegri & Iverson, 1989). Between every step, the samples were centrifuged. The samples were then washed with de-ionized water and digested again, this time with KOH to eliminate organic matter. The samples were then washed again with de-ionized water, and the pollen was separated from non-polleniferous material using Sodium polytungstate (SPT) via density separation (Zabenskie *et al.*, 2006). Concentrated HF was then added to the samples to eliminate silica. The samples were washed again with water, and glacial acetic acid (GAA) was added in preparation for acetolysis. Acetolysis solution (9:1 mixture of acetic anhydride and sulfuric acid) was then added to the samples and the samples were washed again with GAA and then with de-ionized water. The samples were then washed with 95% ethanol and stained with saffranin. Tert-butanol (TBA) was added to the samples before they were transferred finally into vials and left to allow the TBA to evaporate. Final storage was in silicone oil.

For counting, small aliquots of the processed sediment were placed on slides, and covered by a coverslip that was fixed into place with nail varnish. The pollen was then identified and counted under a microscope at 400x. Oil immersion (1000x) was used for critical identification. Identifications were be based on comparisons with modern reference material, as well as on the keys provided by McAndrews *et al.* (1973), Faegri & Iverson (1989), Kapp (2000), and Moore & Webb (1978; Appendix A).

To obtain a good approximation of the composition of the parent vegetation community from fossil pollen analysis, a minimum of 500 grains is typically counted (Birks & Birks, 1980). In sediment samples from high latitudes, pollen analysis is usually complicated by low concentrations of pollen in lake sediments, caused by the low density and productivity of plants on the landscape. For this reason, fewer than 500 grains are sometimes counted in pollen studies of lakes in the high arctic. Low pollen concentrations are rarely a problem in samples from the boreal forest (Gajewski *et al.*, 1995). In this study, a minimum sum of 500 grains was counted for each level in the sediment, where possible.

3.2.3 Charcoal analysis

Microcharcoal analysis was conducted as a part of standard pollen analysis, and so the sampling and preparation techniques that have just been outlined for the enumeration of pollen also apply to the analysis of microcharcoal done in this study. Particles of microcharcoal are preserved on pollen slides and so can be counted in a similar fashion as pollen grains. Using this technique, every charcoal particle on the slide greater than $50\mu m^2$ in size was counted (Whitlock & Larsen, 2001). Microcharcoal fragments were identified based on their appearance on the slide; they are usually visually distinctive as opaque, angular, black fragments that break easily into smaller angular fragments when pressure is applied (Whitlock & Larsen, 2001). The concentration of microcharcoal particles was then calculated in the same way as pollen concentrations, and the microcharcoal influx was then calculated by multiplying the charcoal concentration at any level of the sediment by the sedimentation rate (cm yr^{-1}) at that level (MacDonald *et al.*, 1991). Peaks in the microcharcoal influx are interpreted as periods of high regional fire frequency (Whitlock & Larsen, 2001).

For macrocharcoal analysis, 5cc of sediment were sub-sampled from the core at continuous 1cm intervals, deflocculated using 5% sodium hexametaphosphate, and sieved through a 125 µm sieve (Whitlock & Larsen, 2001). The sediment remaining on the sieve was then placed into Petrie dishes and macrocharcoal particles were counted under a stereomicroscope at various levels of magnification from 10.5-45x. The computer program Charster (http://geography.uoregon.edu/gavin/) was used in order to identify individual local fire-events and to calculate fire recurrence intervals for the record. Charster is designed to ease the analysis of lake-sediment macrocharcoal records when the purpose is to identify peaks that are the result of local fires. The general approach is to separate the "secondary" slowly varying background charcoal influx from the "primary" peak component that indicates the occurrence of individual fires. Secondary charcoal is estimated by the application of a mathematical function to the charcoal series. The background charcoal is then separated from the primary charcoal by difference or ratio, and a threshold is set to isolate significant peaks in the peak component. The charcoal time series may be manipulated in various ways before analysis is undertaken, and a number of options are given for the calculation of the background charcoal curve and the peak identification threshold. Once fire peaks are identified, options are available that allow the analyst to evaluate the validity of the results. The macrocharcoal influx record from Lake WA01 was divided into background and peak components using a loess function with a smoothing window of 500 years. Significant peaks were identified by subtracting the background component from primary charcoal influx at each level. A peak detection threshold of 0.2 was found to exclude insignificant peaks most effectively. The size of the peak smoothing window was found to have no effect on the number of fire events identified by the program.

3.2.4 Chronology

^{210}Pb

Lead-210 dating is the most widely used technique for the dating of lake sediments deposited in the last 150 years (Cohen, 2003). ^{210}Pb has a half-life of 21.6 years, and is a naturally occurring radioisotope in the ^{238}U decay chain. The radioactive daughter isotope of ^{238}U, ^{226}Ra, decays into ^{210}Pb primarily in the ground. Some ^{226}Ra, however, decays into ^{222}Rn gas, which is then released to the atmosphere where it completes its decay into ^{210}Pb. ^{210}Pb produced by the decay of ^{222}Rn in the atmosphere is termed "unsupported" ^{210}Pb. Unsupported ^{210}Pb is then deposited to the ground and into water bodies, where it is incorporated into the sediment (Appleby, 2001). "Supported" ^{210}Pb is produced in the ground by decay of ^{226}Ra and can be assumed to be in equilibrium with its parent isotope. Extra accumulation of unsupported ^{210}Pb can therefore be quantified and can be used to determine the age of the sediment using a ^{210}Pb supply model.

The constant rate of supply (CRS) model is most common supply model that is used in the dating of recent sediments using ^{210}Pb. This model assumes that the supply of unsupported ^{210}Pb has remained constant through time (Appleby, 2001). Lower concentrations of ^{210}Pb are interpreted to indicate higher sedimentation rates.

The uppermost 15 centimeters of sediment taken from Lake WA01 were sent to the Environmental Radiochemistry Laboratory of the Department of Soil Science at the University of Manitoba for lead-210 analysis. The constant rate of supply (CRS) model was used in order to assign ages to the ^{210}Pb values.

Radiocarbon dating

^{14}C has a half-life of 5,730 years and is effective for dating sediments up to 40,000 years old (Smol, 2002). The ^{14}C radioisotope is produced in the earth's upper atmosphere through the bombardment of ^{14}N by cosmic rays. Once produced, ^{14}C is oxidized and transformed into $^{14}CO_2$. Along with its stable sister isotope ^{12}C, ^{14}C is taken up by plants and is incorporated into their physical structure, so that the ratio of ^{14}C to ^{12}C in the structures of plants (as well as in the bodies of animals who eat the plants, and in the bodies of animals who eat the other animals) is approximately in equilibrium with the ratio of ^{14}C to ^{12}C in the atmosphere while the organism is alive (Smol, 2002). When the organism dies, the ^{14}C begins to decay, changing the ^{14}C to ^{12}C ratio. By determining the amount of ^{14}C that is left in a sample relative to the amount of ^{12}C that it contains, and comparing this to a "modern" ^{14}C to ^{12}C ratio, it is possible to determine the time when the organism died, and thus when the layer of sediment in which it was found was deposited (Lowe & Walker, 1997). The technique assumes that the proportion of ^{14}C to ^{12}C in the atmosphere has remained more-or-less constant over time, and that organic material is deposited into a lake soon after it has died.

The Accelerator Mass Spectrometry (AMS) radiocarbon dating technique separates the ^{14}C within a sample from other isotopes by firing Cs ions at a metal disc on which the sample (converted to graphite) has been mounted (Lowe & Walker, 1997). The bombardment of the disc with Cs will cause the ^{14}C to produce negatively charged carbon atoms that are then accelerated towards a positive receptor terminal. ^{14}N, because it will not form negatively charged ions when bombarded with Cs, is thus separated from the ^{14}C signal. This step is particularly important, as ^{14}N tends to mask the ^{14}C signal if not properly separated. Passage through a "stripper" converts the negatively charged carbon atoms to positively charged atoms, and removes other molecules. The carbon atoms are then accelerated again towards a magnet, where ^{12}C, ^{13}C (another isotope of carbon), and ^{14}C are separated by mass (Lowe & Walker, 1997). The AMS technique requires very little material (~1 mg), and thus is ideal for lake sediment work where the amount of organic material in the sediments can sometimes be very low.

Six radiocarbon-14 dates were obtained from Lake WA01 and were used in order to assign ages to the sediments. The dates were determined using the Accelerator Mass Spectrometry technique, and were calibrated to calendar years BP using CALIB 5.0.2 (http://calib.qub.ac.uk/calib) and the Intcal04 calibration curve (Reimer *et al.*, 2004). AMS dating was completed by Beta Analytic, Inc. in Miami, Florida.

The best materials for ^{14}C dating are terrestrial macrofossils (such as twigs or seeds), followed by aquatic plants, aquatic animals, and finally bulk sediments (MacDonald *et al.*, 1991). All of the six dates that were obtained from Lake WA01 were based on the analysis of twigs and wood fragments found in the sediments.

White River Ash

The White River Ash is a volcanic tephra layer that was deposited over a large portion of southeastern Alaska and the southern Yukon 1,147 cal yrs BP (Clague *et al.*, 1995; Robinson, 2001). The source of the eruption has been determined to be Mt. Churchill, located in the St. Elias Mountains in southeastern Alaska (Richter *et al.*, 1995). Using magnetic susceptibility, the White River Ash can be detected in many sediment sequences from the southwest Yukon (e.g. Lacourse & Gajewski, 2000), into the central Yukon, and across into the Northwest Territories (Bunbury & Gajewski, 2009b). The depth of the ash in the WA01 core was included in the age-depth curve in this study, providing further chronological control for the development of the age-depth curve.

Development of the age-depth curve

Age-depth curves are calculated from ^{210}Pb and calibrated ^{14}C dates to provide a means of assigning ages to each depth in a lake sediment core (Smol, 2002). A number of techniques can be used to interpolate between dates to develop a continuous profile. The simplest and most commonly used method is linear interpolation, wherein intermediate levels in the sediment are assigned ages based on their position on a straight line fitted between the closest bracketing radiocarbon dates. The use of a polynomial or loess curve has the benefit of smoothing over the sharp changes in sedimentation rate caused by linear interpolation, and is likely to provide a more reasonable representation of the true pattern of sediment accumulation in a lake for this reason (Smol, 2002). In this study, a number of possible interpolation functions were examined. Ultimately, a loess smoother with a span of

0.9 was applied to the data in order to provide a continuously interpolated age-depth curve for the core.

3.3 Analytical and statistical methods

Climate reconstructions

Pollen-based temperature and precipitation reconstructions for the WA01 core were developed using the Modern Analogue Technique (MAT). The MAT works by calculating the dissimilarity that exists between the fossil and a number of possible modern "analogue" assemblages (Overpeck *et al.*, 1985). Each of the modern assemblages is associated with a set of modern environmental conditions recorded at the time of sampling. The best of the possible modern analogues is (are) then chosen and used to produce quantitative reconstructions of climate or other environmental parameters for the fossil record. For this analysis, the fossil pollen sum from each level in the sediment was calculated excluding non-regional and non-local pollen and spores, as well as those contributed by aquatic plants. A number of the remaining fossil pollen taxa were grouped together so that the fossil data would be organized in a comparable way to the modern analogue data set (Appendix B). Modern pollen assemblages and records of their associated environmental conditions were obtained from the North American Modern Pollen Database (NAMPD; Whitmore *et al.* 2005). This database contains over 4,000 modern pollen assemblages from across North America, representing 134 different pollen taxa. A subset of the information contained in the NAMPD was extracted for this analysis that limited the modern dataset to sites in western and northwestern Canada and Alaska between 50°0' to 75°0'N and 110°0' to 167°3'W. The computer program C2 (http://www.campus.ncl.ac.uk/staff/Stephen.Juggins/) was used in order to perform the reconstruction. The dissimilarity of the fossil pollen assemblages to the modern "analogue" assemblages in the analysis was evaluated using the squared chord distance (SCD) metric. This is the most commonly used dissimilarity measure that is used in the context of the MAT (Sawada, 2006); an SCD of 0 represents a perfect analogue. A weighted average of the three best analogues (Williams & Shuman, 2008) as determined by the analysis was used in order to quantitatively reconstruct the mean July temperature and mean annual precipitation of each level in the core.

Principal components analysis

Detrended correspondence analysis (DCA) indicated that gradient lengths were sufficiently short to make linear ordination via principal components analysis appropriate (first axis = 1.9 SD units; Shaw, 2003). Taxon abundances were not transformed for the DCA, though rare species were down-weighted prior to ordination.

Principal Components Analysis (PCA) is a data visualization technique that allows the observation of trends in a multivariate dataset (Shaw, 2003). New axes are generated for the dataset that are centered on its overall mean and then rotated so that each successive axis accounts for the maximum remaining variance in the data. The first few axes are thus the most valuable in summarizing the dataset as a whole and are composed of a portion of the variance of each of the data's original variables (Shaw, 2003).

Principal components analysis (PCA) was performed on the results of fossil pollen analysis from the WA01 core. A pollen sum of local and regional pollen types was used in the PCA, and a number of the taxa were also grouped together in order to reduce clutter on the resulting biplots (Appendix B).

Data plotting

The results of sediment, pollen, microcharcoal, and macrocharcoal analysis are presented as stratigraphic diagrams. Magnetic susceptibility and loss-on-ignition data are plotted together, along with the results of micro and macrocharcoal analysis. The major pollen types present in the core are presented in a second diagram as percentages of the pollen sum. Pollen influx is plotted in a third diagram. The results of quantitative climate reconstruction using the pollen data are also presented in this way. The results of principal components ordination analysis are shown in biplots and stratigraphic diagrams illustrating the species loadings and sample scores.

Chapter 4 – A high-resolution vegetation, fire, and climate history from the Aishihik Region, Yukon Territory, Canada

Abstract

Paleocological studies based on the analysis of lake sediments offer the potential for high resolution and well-dated records of past environmental conditions. A 2.7 m sediment core from Lake WA01, southwest Yukon, Canada (unofficial name, 61°14'41"N, 136°55'35"W, 1000 m.a.s.l.) documents the post-glacial vegetation, fire, and climate history of the region. The earliest portion of the WA01 record was characterized by the establishment of open birch-shrub tundra at the study site. *Picea glauca* then established ca. 9,900 cal yrs BP, and has since remained dominant on the landscape. Progressively decreasing precipitation in the region over the last ca. 9,000 years, noted in a previous study by Viau *et al.* (2008), is not captured in the Lake WA01 climate reconstructions. From ca. 9,900 cal yrs BP to the present day, reconstructed mean July temperatures and total annual precipitation at the study site remained essentially constant. A short period of low total annual precipitation is noted from deglaciation at 10,500 cal yrs BP to 9,900 cal yrs BP. The regional-scale fire regime surrounding the study site increased gradually in intensity over the course of the Holocene. Local fires in the area immediately surrounding the study lake decreased gradually in frequency and/or size over the course of the Holocene, though the exact cause remains unclear. An alternating pattern in the sediment loss-on-ignition from Lake WA01 is related to similar trends in $\partial^{18}O$ values from the Mount Logan oxygen isotope record. Based on a positive association between sediment carbonate content and enriched $\partial^{18}O$ values from the Mount Logan record, it is proposed that periods of increased and decreased

sediment carbonate content in the WA01 core are indicative of wetter and drier conditions at the study site, respectively.

4.1 Introduction

Over the course of the 20th century, the northern climate has shown significant warming, with some locations registering an increase in air temperatures of up to 5°C since the turn of the last century (IPCC, 2007). Climate models consistently predict "substantial" further increases in temperature during the 21st century, with potentially significant outcomes for northern ecosystems.

It is important for us to understand how the current global warming fits in to the larger context of climate change over the history of the Earth. In order to do this, we need paleoclimate records that predate the 20th century. Historical proxy-climate records from lake sediment provide one way for us to place the current warming into a larger temporal frame of reference.

Due to the sequential accumulation of lake sediments, lake sediment cores can provide long-term records of the environment (Smol, 2002). Fossil pollen recovered from lake sediments and other depositional environments is a common proxy used to reconstruct the composition of past vegetation communities (Faegri & Iverson, 1989). Since the vegetation in a region is related to the climate, fossil pollen can be used to provide quantitative reconstructions of climatic variables such as temperature and precipitation (e.g. Sawada *et al.*, 2004; Viau *et al.*, 2006; Willard *et al.*, 2007; Minckley *et al.*, 2007; Zabenskie & Gajewski, 2007; Bunbury & Gajewski, 2009a).

A number of pollen diagrams have been presented for sites across northwestern Canada and Alaska (e.g. Wang, 1989; Lacourse & Gajewski, 2000; Cwynar, 1982, 1988; Cwynar & Spear, 1991, 1995; Szeicz & MacDonald, 2001; Stuart *et al.*, 1989; Birks, 1980; Keenan & Cwynar, 1992; Bourgeois & Guerts, 1983; Rampton, 1971; Carlson & Finney, 2004; Ritchie, 1982; Pisaric *et al.*, 2001; Cwynar & Ritchie, 1980; Wang & Guerts 1991a, b; Bunbury & Gajewski, 2009a). The temporal resolution of these studies, however, is often quite low due to the long time that they take to complete. The spatial density of paleoenvironmental records is also low in many parts of the Canadian North, necessitating further study.

In addition to changes to mean temperature and precipitation, other aspects of modern climate change that are important for us to consider are the changes to extremes and disturbances which are likely to be associated with the development of new climate regimes in the Canadian North and around the world in the coming years. It is unclear how modern climate change will impact the frequency of disturbances such as fire in the future (Hu *et al.*, 2006). Fire is an important agent of disturbance in the Canadian boreal forest, and plays an important role in the renewal of the stand and the maintenance of diversity (Aber & Melillo, 2001). Similar to the role that pollen analysis plays in understanding vegetation and climate history, paleocharcoal studies can provide insights into the history and frequency of fires in a region by the quantification of charcoal particles preserved in lake sediments (Whitlock & Larson, 2001).

This paper presents a high-resolution pollen diagram from the Aishihik region of the southwest Yukon Territory, Canada, derived from the analysis of pollen deposited in the sediment of a small lake. The results of microscopic and macroscopic charcoal analysis are also presented to provide a high-resolution fire history for the region. A statistical comparison of pollen assemblages from the core with modern data available from the North American Modern Pollen Database (Whitmore *et al.*, 2005) has also been used to derive temperature and precipitation reconstructions down-core for the period covered by the sediment record. These inferred climate records are then related to independent records of climate from the Mount Logan ice cores (Fisher *et al.*, 2008).

4.2 Regional setting

Lake WA01 (unofficial name; 61°14'41"N, 136°55'35"W, 1000 m.a.s.l.) is located between the Ruby Range and Klondike Plateau in the Aishihik region of the southwest Yukon Territory (Figure 4.1). Lake WA01 is a small closed-basin lake with an area less than 0.1 ha and a maximum depth during the summer of 2008 of approximately 1 m. Evidence of previous shorelines was clearly visible around the lake at the time of coring, suggesting that at one time the lake may have been significantly larger and deeper than it was at the time the core was collected (Figure 4.2). Similar marks of previous shorelines are found around many lakes in the area, suggesting a prolonged dry period that is confirmed by local residents. A pH of 8.22 and water conductivity of 284 μScm^{-1} was measured on the date of coring on July 17th, 2008.

The area surrounding the study lake is underlain by Precambrian-Paleozoic sedimentary bedrock of the Cordilleran orogen, and is in a region of extensive discontinuous permafrost (50-90%). Surface material is comprised of till blankets (Fulton, 1995). Mean annual temperature in the study area is below 0°C, and precipitation is below 300 mm per year, resulting in a cold, semi-arid climate (National Atlas Information Service, 1995; Table 4.1). The region has a variable topography characterized by high ridges and hills surrounding numerous low-lying depressions. The study lake itself is located in a small depression surrounded by steep forested slopes on all sides.

The vegetation surrounding the study site is characterized by the presence of low-density boreal forests dominated by white spruce (*Picea glauca*). White spruce stands in the region tend to be found on well-drained soils such as on the sides and tops of slopes. Stands of poplar and aspen (*Populus*) as well as birch (*Betula*) and alder (*Alnus*) are also common, particularly in low-lying areas and on more poorly drained sites (Wang, 1989). The understory includes shrubs such as juniper (*Juniperus*) and willow (*Salix*) as well as numerous herbaceous plants such as species of grasses (Poaceae) and sedges (Cyperaceae); these taxa often tend to occur on more poorly drained sites. *Epilobium* and *Shepherdia* are particularly noticeable components of the modern vegetation, and are principally found on well-drained soils.

Between 1960 and 2000 AD, 205 fires burned in the region around the study lake over an area of 195 km^2 (McCoy & Burn, 2005). Lightning strikes accounted for 5.9% of these. Seventy percent of the fires that occur each year burn during the months of June, July, and August.

4.3 Methods

A lake sediment core was collected from Lake WA01 using a 5 cm diameter, 1 m long Livingstone square-rod piston sampler (Wright, 1967), from a raft anchored at three points to the lake shore. The uppermost meter of sediments was collected using a plastic tube fitted with a piston to ensure that the sediment-water interface remained undisturbed. The topmost unconsolidated sediments were extruded in the field into plastic bags at 0.5 cm intervals, using a portable extruding device. The remaining sediment was extruded in the field, wrapped in plastic wrap and aluminum foil, and stored in split PVC tubing before being transported back to the field research station. The core was then shipped to Ottawa and stored in a refrigerator at 4°C until analysis.

Using a calibrated brass sampler, 0.5 cm^3 of sediment was sub-sampled from the core at continuous 1 cm intervals for loss-on-ignition analysis (Dean, 1974). The samples were ignited at 550°C for four hours and at 950°C for a further two hours to obtain estimates of the organic and carbonate content. Whole core magnetic susceptibility was measured using a Bartington MS2C Core Sensor at 1 cm increments down the entire length of the core.

Pollen preparation followed the protocol outlined by Faegri & Iverson (1989) with the addition of heavy liquid separation (Zabenskie *et al.*, 2006). Sediment was sub-sampled at 1- 7 cm intervals along the core for analysis. Pre-acetolyzed *Lycopodium* tablets were added to the samples prior to processing to allow the calculation of pollen and microcharcoal concentrations (Bennett & Willis, 2001). The treatment includes 10% HCl, 10% KOH, the heavy liquid Sodium polytungstate (SPT), concentrated HF, and acetolysis solution. In heavy liquid separation, pollen grains were separated from the sediment matrix using Sodium polytungstate with a specific gravity of 1.95 prior to being digested in HF. Final storage was in silicone oil. For pollen identification and counting, small aliquots of the processed sediment were placed on slides, and the pollen was identified and counted under a microscope at 400x, with oil immersion (1000x) used for critical identification. Identifications were be based on comparisons with modern reference material, as well as on the keys provided by McAndrews *et al.* (1973), Faegri & Iverson (1989), Kapp (2000) and

Moore & Webb (1978). A minimum sum of 500 grains was counted for each level in the sediment where possible.

Microcharcoal analysis was conducted as a part of standard pollen analysis. All fragments appearing on the pollen slides greater than 50 μm^2 were counted. Microcharcoal particles were identified based on their appearance on the slide; microcharcoal fragments are usually visually distinctive as opaque, angular, black fragments that break easily into smaller angular fragments when pressure is applied (Whitlock & Larsen, 2001). The concentration of microcharcoal particles was then calculated in the same way as pollen concentrations, and the microcharcoal influx was then calculated by multiplying the charcoal concentration at any level of the sediment by the sedimentation rate (cm yr^{-1}) at that level (MacDonald *et al.*, 1991). Peaks in the microcharcoal influx are interpreted as periods of high regional fire frequency occurring in the Aishihik Basin over the course of the Holocene (Whitlock & Larsen, 2001).

For macrocharcoal analysis, 5cc of sediment were sub-sampled from the core at continuous 1cm intervals, deflocculated using 5% sodium hexametaphosphate, and sieved through a 125 µm sieve (Whitlock & Larsen, 2001). The sediment remaining on the sieve was then placed into Petrie dishes and macrocharcoal particles were counted under a stereomicroscope at various levels of magnification from 10.5-45x. The computer program Charster (http://geography.uoregon.edu/gavin/) was used to identify individual local-scale fire-events occurring in the watershed of the study lake, and to calculate fire recurrence intervals. The general approach is to separate the "secondary" slowly varying background charcoal influx from the "primary" peak component that indicates the occurrence of individual fires. Secondary charcoal is estimated by the application of a mathematical function to the charcoal series. The background charcoal is then separated from the primary charcoal by difference or ratio, and a threshold is set to isolate significant peaks in the peak component. The charcoal time series may be manipulated in various ways before analysis is undertaken, and a number of options are given for the calculation of the background charcoal curve and the peak identification threshold. Once fire peaks are identified, options are available that allow the analyst to evaluate the validity of the results. The macrocharcoal influx record from Lake WA01 was divided into background and peak components using a loess function with a smoothing window of 500 years. Significant peaks were identified by subtracting the background component from primary charcoal influx at each level. A peak detection threshold of 0.2 was found to exclude insignificant peaks most effectively. The size of the peak smoothing window was found to have no effect on the number of fire events identified by the program.

The chronology of the core was determined through ^{210}Pb and ^{14}C dating of the sediment. The uppermost 15 centimeters of sediment were sent to the Environmental Radiochemistry Laboratory of the Department of Soil Science at the University of Manitoba for lead-210 analysis. The constant rate of supply (CRS) model was used in order to assign ages to the ^{210}Pb values. Six accelerator Mass Spectrometry (AMS) radiocarbon-14 dates were obtained from Lake WA01 to assign ages to the remaining sediments of the core. The dates were calibrated to calendar years BP using CALIB 5.0.2 (http://calib.qub.ac.uk/calib) and the Intcal04 calibration curve (Reimer *et al.*, 2004). AMS dating was completed by Beta Analytic, Inc., in Miami, Florida. The age (1,147 cal yrs BP) and depth of the White River Ash (Clague *et al.*, 1995; Robinson, 2001) was also used to further chronological control for the sediments. A loess smoother (span = 0.9) was applied to the data in order to provide a continuously interpolated age-depth curve for the core.

The pollen sum from each level in the sediment was calculated excluding non-regional and non-local pollen and spores, as well as those contributed by aquatic plants. Pollen-based temperature and precipitation reconstructions for the WA01 core were estimated using the Modern Analogue Technique (MAT). Modern pollen assemblages and records of their associated environmental conditions were obtained from the North American Modern Pollen Database (NAMPD), presented by Whitmore *et al.* (2005). A subset of the information contained in the NAMPD was extracted for the analysis that limited the modern dataset to sites in western and northwestern Canada and Alaska between 50°0' to 75°0'N and 110°0' to 167°3'W. The dissimilarity of the fossil pollen assemblages to the modern "analogue" assemblages in the analysis was evaluated using the squared chord distance (SCD) metric (Sawada, 2006). A weighted average of the three best analogues as determined by the analysis was used in order to quantitatively reconstruct the mean July temperature and mean annual precipitation of each level in the core (Williams & Shuman, 2008).

Detrended correspondence analysis (DCA) indicated that gradient lengths were sufficiently short to make linear ordination via principal components analysis appropriate (first axis = 1.9 SD units; Shaw, 2003). Taxon abundances were not transformed for the DCA, though rare species were down-weighted prior to ordination. Principal components analysis (PCA) was performed on the results of fossil pollen analysis from the WA01 core. A pollen sum of local and regional pollen types was used in the PCA, and a number of the taxa were also grouped together in order to reduce clutter on the resulting biplots.

4.4 Results

4.4.1 Sediment stratigraphy and chronology

A 270 cm sediment core was recovered from Lake WA01 (unofficial name) during the summer of 2008. The uppermost 165 cm of the core consisted of medium brown-coloured gyttja. The calcareous shells of numerous small mollusks were clearly visible in this portion of the sediment from approximately 55 to 75 cm, 95 to 110 cm, and 140 to 160 cm. From 165 to 235 cm, the sediment in the core was darker in colour, with no visible shells, but with visible fine laminations. From 235 to 255 cm, the core reverted to lighter brown sediments similar in appearance to those of the uppermost 165 cm of the sequence. Fine laminations were apparent, as well as numerous mollusk shells. The basal sediments from 255 to 270 cm were dark grey to black coarse inorganic sediments, with no lamination or shells apparent. The White River Ash (WRA; Clague *et al.*, 1995), identified by magnetic susceptibility and by the presence of visible ash particles, was located in a band between 53 and 60 cm.

Radiocarbon and ^{210}Pb dating of the sediment provided a reliable chronology with no age reversals and an approximately linear age-depth sequence (Tables 4.2, 4.3; Figure 4.3). Interpolation using a loess smoother with a span of 0.9 gave a basal date of ca. 10,500 cal yrs BP. The sedimentation rate remained approximately constant at 0.02 cm/year from approximately 25 cm depth to the base of the core. From 25 cm to the top of the core, the rate of deposition began to increase gradually to its maximum value of 1.1 cm/year in the topmost portion of the sediment, though this is likely an artefact of increased dating control at these levels. Magnetic susceptibility remained uniformly low throughout the core, with the exception of the basal sediments and at the depth of the WRA.

The organic and carbonate content of Lake WA01 appears to have alternated between two states over the course of the record. In the first of these two states, the percentage of organic material in the core tended to be relatively high, and carbonate content was low; in the second state, the reverse was true. Periods of high carbonate content were often noted at the same depths at which mollusk shells were found, though large amounts of carbonate material were also found at levels in the sediment where no shells were apparent.

From 10,500 approximately 9,500 cal yrs BP, the proportion of carbonate material in the sediment decreased gradually from 22% to approximately 5% (Figure 4.4). The amount of organic material in the core increased concurrently with the decrease in carbonate content at these levels. From 9,500 to 6,200 cal yrs BP, carbonate content remained low and organic content remained high. Carbonate content was also decreased from 5,200 to 4,200 cal yrs BP, and organic content was increased. From 4,200 to 2,500 cal yrs BP, carbonate content decreased gradually, and was paralleled by gradually increasing organic content in the core.

From 6,200 to 5,200 cal yrs BP, the percentage of carbonates in the WA01 core was relatively high for a period of approximately 1,000 years, peaking at ca. 15%. Organic content in the core was low at this time. The percentage of carbonate material in the sediment was also increased from 4,200 to 3,200 cal yrs BP, and from 2,500 to 1,400 cal yrs BP. At the depth of the WRA, both carbonate and organic content were low. Above the ash layer, carbonate content slowly increased, and organic matter quickly increased, such that the core reverted at this time to its low carbonate/high organic state, which continued to the top of the sediment.

4.4.2 Microcharcoal and macrocharcoal stratigraphy

Microcharcoal influx to the lake sediment, used to interpret regional fire frequency in the Aishihik Basin as a whole, was highly variable over the course of the WA01 record at the scale of hundreds of years (Figure 4.4). The application of a loess smoother with a span of 0.2, however, illustrates longer-term trends in the data; the results show a gradual increase in microcharcoal influx from the beginning of the sedimentary sequence to the present day, from ca. 800 particles/cm^2/yr to ca. 1,200 particles/cm^2/yr by 150 cal yrs BP. A large increase in microcharcoal influx, to ca. 7,000 particles/cm^2/yr, occurred in the last 150 years of the record that can be attributed to the large increase in the sedimentation rate that was also noted in the topmost levels of the WA01 core (above).

The program Charster identified the occurrence of 22 local (i.e. occurring with the watershed of the study lake) fires over the course of the WA01 macrocharcoal record. Average macrocharcoal influx decreased gradually over the length of the WA01 core from ca. 0.5 particles/cm^2/yr at the beginning of the record to 0.3 particles/cm^2/yr by 150 cal yrs BP (Figures 4.4, 4.5). As in the microcharcoal record, a large increase in macrocharcoal influx occurred from ca. 150 cal yrs BP to the present (average = 0.8 particles/cm^2/yr), which can be attributed to the increased sedimentation rate that has been calculated for the topmost levels of the core.

The mean fire recurrence interval (MFI) at Lake WA01 declined gradually from the beginning of the record to the present day, concurrently with gradually decreasing macrocharcoal influx values. The MFI at Lake WA01 was significantly shorter early in the record (MFI = ca. 280 yrs) than in its latter portions (MFI = ca. 720 yrs). Two fires were identified in the last 50 years of the record that can be attributed to the large increase in macrocharcoal influx in the uppermost levels of the core that has been noted above.

4.4.3 Pollen stratigraphy

Prior to 9,900 cal yrs BP, the pollen assemblages of the WA01 core were dominated by relatively high percentages of *Betula* (max 68%) pollen. *Alnus crispa* (max 12%), *Salix* (max 8%), Poaceae (max 6.5%), and Cyperaceae (max 5%) pollen also formed relatively important parts of the assemblages during this time (Figure 4.6). *Betula* pollen reached its maximum for the period of the record in this earliest part of the core.

At 9,900 cal yrs BP, the abundance of *Picea glauca* pollen increased significantly in the pollen assemblages (max 80%). *Betula*, *Alnus crispa*, and Poaceae pollen all declined at this time, while *Salix* and Cyperaceae pollen remained at approximately constant mean values. The abundance of *Picea glauca* pollen in the WA01 core showed significant high-frequency variability at the scale of hundreds of years after its first arrival, however these variations were not sufficiently great at any time in the record to cause *Picea glauca* to be replaced as the dominant taxon in the pollen assemblages. White spruce has thus remained the dominant pollen within the WA01 core from 9,900 cal yrs BP to the present day. Small variations in the assemblage composition occurring after 9,900 cal yrs BP could often be attributed to small changes in the abundance of *Picea glacua* pollen, and to corresponding changes to the representation of pollen taxa such as *Betula* (max 36%), *Alnus crispa* (max 10.6%), Poaceae (max 4.5%), and Cyperaceae (max 2.5%), which tended to show a negative relationship with *Picea glauca* pollen abundance throughout the WA01 record. *Juniperus* and *Salix* pollen, and spores of *Sphagnum* and Polypodiaceae tended to decline in abundance when *Picea glauca* pollen abundance was reduced, but remained at very low levels throughout the record. *Epilobium* and *Shepherdia* pollen both occurred only rarely in the pollen record, and remained at abundances no greater than 2.5%. Pollen taxonomic diversity as measured by the Shannon-Weiner index was negatively correlated to the percent abundance of *Picea glauca*. However, due to the multiple levels of taxonomic precision present in the pollen data, it is unclear how this should be interpreted and it will not be considered further.

With the exception of the early portion of the record, *Picea glauca* dominated the pollen influx to the WA01 core (Figure 4.7). *Betula* pollen influx was high early in the record but declined quickly with the arrival of *Picea glauc*a and remained low for the remainder of the sequence. Total pollen influx in the WA01 core was extremely low for the region, and was variable through the majority of the record (average ca. 350 grains/cm^2/yr). At ca. 150 cal yrs BP, total pollen influx increased sharply to an average value of ca. 2,500 grains/cm^2/yr; this dramatic increase in influx can once again be attributed to the increased sedimentation rate that has been calculated for the uppermost levels of the sediment, as was the case in the microcharcoal and macrocharcoal records. Total pollen influx was also very slightly decreased in the earliest portions of the record and between ca. 10,500 and 9,900 cal yrs BP.

4.4.4 Numerical Analyses

Climate reconstructions

Mean July temperatures, reconstructed using the modern analogue technique (MAT) ranged between 9.7 and 14.8°C (Figure 4.8) prior to 9,900 cal yrs BP, however, squared-chord distances (SCD) were generally elevated at this time, suggesting that the reconstruction is less reliable at these levels of the core. The particularly high reconstructed mean July temperatures in this portion of the record can be attributed to the influence a few of the modern sites selected as analogues at these depths. July temperatures decreased to an average temperature of ca. 12.5°C between 9,900 and 6,200 cal yrs BP. Temperatures in the middle Holocene, from 6,200 to 2,500 cal yrs BP, were slightly higher (ca. 13°C), and declined once again between 2,500 cal yrs BP to the present, to approximately 12.5°C on average. Mean July temperature thus varied very little over the course of the Holocene at the study site from 9,900 cal yrs BP to the present day. Dissimilarity values typically remained below 0.15, although levels in which higher temperatures are reconstructed often correspond to increased SCD values.

Total annual precipitation increased sharply from low values of ca. 220mm/yr to ca. 380 mm/yr from the beginning of the record to 9,900 cal yrs BP. Total annual precipitation remained approximately constant from this time to the end of the record at values ca. 370-380mm/yr.

Principal Components Analysis

A principal components analysis (PCA) was performed on the fossil pollen analysis results from the WA01 core. The first two axes explained 22 and 14% of the variation in the data, respectively (Tables 4.4-4.6). Taxa positively loaded on both the first and second axis included *Betula*, *Salix*, Poaceae, *Alnus crispa*, Cyperaceae, Polypodiaceae, *Juniperus*, and *Sphagnum* (Figure 4.9). *Picea glauca*, *Epilobium*, and *Shepherdia* were negatively loaded on both Axis 1 and Axis 2. *Populus* and *Pinus diploxylon* were both positively loaded on the first axis, and negatively loaded on the second axis.

4.5 Discussion

Vegetation

The earliest portion of the WA01 record (>9,900 cal yrs BP) was characterized by the presence of high proportions of *Betula* pollen, along with *Alnus crispa*, *Salix*, Poaceae, and Cyperaceae, suggestive of the presence of birch-shrub tundra on the landscape in the first ca. 600 years after deglaciation. Birch shrub-tundra establishment in the southwest Yukon soon after deglaciation is also reported by Lacourse & Gajewski (2000). Wang (1989) also interprets the establishment of birch shrub-tundra ca. 10,000 ^{14}C yrs BP at nine sites in the northern and southwestern Aishihik region. The very slight decrease in total pollen influx that has been noted in this early portion of the record might also suggest the presence of an open tundra environment characterized by lower biological production during this time.

The abundance of *Picea glauca* pollen in the WA01 core increased significantly ca. 9,900 cal yrs BP, and has dominated the pollen record from that time to the present day. The dominance of *Picea glauca* pollen, in combination with small amounts of taxa such as *Betula*, *Salix*, Poaceae, *Alnus crispa*, Cyperaceae, and *Juniperus* suggests that a boreal forest similar in structure and composition to the modern forest has been established in the Aishihik Basin since soon after deglaciation. Lacourse & Gajewski (2000), Wang (1989), and Bunbury & Gajewski (2009a) also note little change in the abundance of *Picea glauca* in the southwest Yukon and Aishihik Basin over the course of the Holocene, though the date of spruce establishment is not the same at any of these sites as at WA01. A principal components analysis (PCA) conducted on the fossil pollen data also suggests that *Betula*, *Salix*, Poaceae, *Alnus crispa*, Cyperaceae, and *Juniperus* have tended to grow together in the past as they do in the modern vegetation, on low-lying and more poorly drained sites. The ordination of *Picea glauca*, *Epilobium* and *Shepherdia* together on the opposite side of the PCA biplot also suggests that they tended to grow together in the past as they do in the modern day on the sides and tops of slopes, and on better-drained soils.

Cwynar & Spear (1991) comment on the ambiguity of the manner and timing of spruce migration into the Yukon since the end of the Wisconsin. Bunbury and Gajewski

(2009a) place the regional-scale establishment of *Picea glauca* at ca. 10,000 cal yrs BP at Upper Fly Lake in the southwest Yukon. Studies of Grayday, Honeymoon, and Monkshood Ponds in the central Yukon indicate that white spruce (*Picea glauca*) was present in the central parts of the Territory by 9,400 ^{14}C yrs BP (Cwynar & Spear, 1991). White spruce is also identified by 9,000 ^{14}C yrs BP in the upper Nisling Valley and Ittlemit Lake Basin, and at 8,600 ^{14}C yrs BP in the southwestern Aishihik Basin (Wang, 1989). Lacourse & Gajewski (2000) interpret spruce establishment at Sulphur Lake in the southwest Yukon at 8,400 ^{14}C yrs BP; a similar date is suggested by Stuart *et al.* (1989) at nearby Jenny Lake, where spruce establishment is placed at 8,500 ^{14}C yrs BP. Lastly, Cwynar (1988) suggests that spruce established at Kettlehole Pond by 9,250 ^{14}C yrs BP, and Rampton (1971) identifies spruce establishment at Antifreeze Pond, at the Yukon-Alaska border at 8,700 ^{14}C yrs BP. The date of spruce establishment at WA01 is thus somewhat earlier than at the sites of other similar studies which have been conducted in the southwest Yukon, though it corresponds well with the date of regional-scale spruce establishment which is inferred by Bunbury and Gajewski (2009a).

Colinvaux (1964), Brubaker *et al.* (2005), and Anderson *et al.* (2006a), among others, suggest that spruce migrated into the study region and the remainder of northern North America from eastern Beringian refugia soon after the end of the last glaciation. An alternate migration route is suggested by Cwynar (1982, 1988), who proposes that spruce migrated north from British Columbia through the Liard and Yukon River systems and then continued northwestward into the southwest Yukon. Lacourse and Gajewski (2000) suggest that spruce may have migrated from northern British Columbia to the Liard River and from there into the Tintina Trench. From the Tintina Trench, the authors then suggest that spruce could conceivably have migrated south and westward into the Aishihik Basin (Lacourse &

Gajewski, 2000). The relatively early date of spruce establishment at Lake WA01 is in agreement with this last potential route of migration. By this path, spruce forests would have established in the southwest Yukon in a pattern moving from east to west and north to south, and thus would most likely have established in the area of the study site at an early date. From Lake WA01, white spruce forests would then have continued on to establish in the remainder of the Aishihik Basin and to migrate westward into the Shakwak Trench by a later date in the post-glacial history of the southwest Yukon.

Trends in regional fire history

Microcharcoal influx to the lake sediment increased gradually over the course of the WA01 record, suggesting a gradual increase to the frequency and/or the size of fires burning in the Aishihik Basin from the end of the last glaciation to the present day. Lynch *et al.* (2003) also note low fire occurrence in the earliest portions of their charcoal record from Dune Lake in interior Alaska, from ca. 9,000-5,500 cal yrs BP, and an increase in fire frequency from 5,500 cal yrs BP to the present, which the authors attribute to the onset of cooler and wetter conditions in their study region, causing the replacement of *Betula-P. mariana-Alnus* vegetation with *P. mariana*-dominated communities more prone to burning. Hu *et al.* (1996) also note decreased fire in the earliest portions of their charcoal record from Farewell Lake in Alaska, and increased fire in the last ca. 6,000 years. Increased fire is again associated with the onset of cooler and wetter conditions at the study site, and with increased occurrence of *P. mariana* in that study. The gradual increase in microcharcoal influx at Lake WA01, however, cannot be attributed to any notable progressive changes to the regional vegetation or pollen-inferred climatic conditions surrounding the study site over the course of the record. Recent climate reconstructions from eastern Beringia (Viau *et al.*, 2008; Kurek *et al.*, 2009), as well as from Dune (Bigelow, 1997), Farewell (Hu *et al.*, 1998), and Birch (Abbott *et al.*, 2000) Lakes in Alaska similarly do not show any significant changes to mean July temperature over the course of the Holocene that might have caused the occurrence of fire to slowly increase in the study region. Viau *et al.* (2008), however, do note progressively decreasing total annual precipitation from ca. 9,000 cal yrs BP to the present in multiple eastern Beringian pollen records, which might have encouraged increased burning across much of the Yukon Territory. Bunbury & Gajewski (2009a) reconstruct gradually decreasing temperatures and increasing precipitation at Upper Fly Lake in the southwest Yukon over the course of the Holocene, though the difference in these variables between the early and later portions of the record is slight (max. difference of 1-2°C and 50mm/yr between 10,000 and 1,500 cal yrs BP), and thus it is unclear whether this represents a true gradual change in climatic conditions. It is also counter-intuitive that frequency and/or size of fires would increase during cooler and wetter periods in the record, unless, as has been mentioned previously, this resulted in a change in the vegetation that would make the environment more susceptible to fire.

Lacking any signs of significant change to the vegetation at the study site over the course of the Holocene, it is perhaps most likely that progressively decreasing precipitation in the study area (as has been suggested by Viau *et al.*, 2008) caused the gradual intensification of the regional fire regime through time, but remained slight enough to not have any noticeable effect on the composition of the plant community. Because the study region is already characterized by relatively arid conditions, it is conceivable that a small change in precipitation would be unlikely to have any great impact on the regional vegetation, which is already adapted to a dry environment. The broad environmental tolerance of boreal forest ecosystems (MacDonald, 2003) also makes it reasonable to suggest that a decrease in precipitation would not have any significant impact on the composition and structure of the vegetation community unless it was a very great change that occurred. Decreased precipitation, however, would have the effect of drying out the landscape, making it more susceptible to burning, and potentially increasing the frequency and/or the size of fires.

In the case that a change to the climate was not significant enough to affect the vegetation at the study site, pollen-based climate reconstructions would also show no clear change to climatic conditions, as has been noted in the WA01 pollen-based climate records which are presented in this study. That no apparent change occurs in the record of reconstructed total annual precipitation at Lake WA01 thus does not contradict the possibility of gradually decreasing precipitation in the region, as such a change would not be reflected in the reconstruction unless the vegetation was affected in some way. The large increase in microcharcoal influx that has been observed in the last 150 years of the WA01 record can be attributed to a similar large increase in the sedimentation rate also occurring in the topmost levels of the sediment, and thus does not represent a real change to the regional fire regime at this time.

Local fire patterns at Lake WA01

In contrast to the regional fire record interpreted from the microcharcoal, macrocharcoal influx to Lake WA01 decreased progressively over the length of the WA01 core, suggesting gradually decreasing incidence of local fires in the watershed immediately surrounding the study lake since the end of the last glaciation. Whittmire (2000) also notes a similar trend in macrocharcoal influx at nearby Keyhole Pond, over the course of that record from 11,000 to ca. 1,000 cal yrs BP, however, the author makes no comment as to what the cause of this decrease might be. As in the WA01 microcharcoal record, the large increase in macrocharcoal influx from ca. 150 cal yrs BP to the present can most probably be attributed to the increased sedimentation rate that has been calculated for the topmost levels of the core, and thus likely does not represent a real change to the local fire regime.

Early in the WA01 record, the mean fire interval in the area immediately surrounding the lake was approximately 280 years. This compares well with the results of other macrocharcoal studies from northwest North America, where MFIs have normally ranged between 200 and 400 years over the course of the Holocene (e.g. Tinner *et al.*, 2006, Lynch *et al.*, 2004, Hu *et al.*, 2006).

In the latter ca. 6,000 years of the record, the MFI at Lake WA01 increased significantly to approximately 720 yrs. Lynch *et al.* (2004) also record MFIs greater than 500 years prior to 3,800 cal yrs BP at Moose and Choksana Lakes in south-central Alaska. By way of explanation, the authors suggest that because their sampling resolution exceeded 40 years per sample in many cases, high charcoal peaks might sometimes have represented multiple fire events, which would have resulted in overestimated MFIs, though this possibility is later rejected (Lynch *et al.*, 2004). The sampling resolution in the WA01 core also generally exceeded 40 years per sample, however, large estimated MFIs also occurred in some cases at levels where the sampling resolution was lower. This would make it unlikely that the sampling resolution is responsible for the large estimated mean fire intervals of the latter 6,000 years of the WA01 record. Lynch *et al.* (2004) also discuss the effect of changing lake-levels as a possibility to account for changes to the frequency of macrocharcoal influx peaks at their study sites through time. The authors suggest that low macrocharcoal influx prior to 3,800 cal yrs BP might be related to the occurrence of higher water levels at the study lakes during this time period, than occurred from 3,800 cal yrs BP to the present. Higher water levels would have led to less intense concentration of macrocharcoal particles in the central areas of the lakes, and thus to decreased macrocharcoal content at these levels of the sediment cores (Lynch *et al.*, 2004). Lynch *et al.* (2004) also discuss the possibility that increased surface runoff in wetter time periods, resulting in increased deposition of background macrocharcoal to the sediment through time, and/or increased sediment mixing and redeposition at different points in the history of the study lakes might mask charcoal peaks by making them indistinguishable from the background influx. This would also result in overestimated MFIs. Lynch *et al.* (2004) reject all of these possibilities, however, as inconsistent with the results of their study. They eventually conclude that their charcoal record accurately reflects the importance of local fire around their study sites through time, but do not make any conclusions as to why the estimated MFIs at their sites were so large prior to 3,800 cal yrs BP, besides to associate increased frequency of fire after this time period with wetter environmental conditions and increased abundance of *Picea mariana* in their study area (Lynch *et al.*, 2004).

Periodically decreased lake water levels would have the effect of concentrating other macrofossils in the lake sediment along with macrocharcoal particles (Lynch *et al.*, 2004). Some sign in the sediment would also be expected if surface runoff was prone to change, or if sediment mixing and redeposition were occurring at different times in the history of a lake. At WA01, no notable progressive change occurs in the sediment stratigraphy or in the concentration of macrofossils that might suggest that the gradual decrease in macrocharcoal influx, and the corresponding increase in the MFI at the study lake through time is an artefact of changing depositional conditions within the lake. There is also no clear gradual change in the WA01 pollen or climate record that would give some indication of external forces acting to change the macrocharcoal influx or the MFI at Lake WA01, nor do climate reconstructions from eastern Beringia (Viau *et al.*, 2008; Kurek *et al.*, 2009), or from Dune Lake (Bigelow, 1997), Farewell Lake (Hu *et al.*, 1998), or Birch Lake (Abbott *et al.*, 2000) in Alaska show any significant gradual changes to temperature or precipitation which might have encouraged decreased burning at the study site in the latter portions of the record. Thus, while the effect of sampling resolution, depositional processes, and/or climatic changes cannot be entirely ruled out, the exact cause of the gradual decrease in macrocharcoal influx over the length of the WA01 core remains unclear.

Relationship between regional and local fire

Trends in microchacoal and macrocharcoal from the WA01 core suggest that few similarities have existed between the regional and local fire regimes surrounding Lake WA01 over the course of the Holocene (r^2 = 0.001 for the time period spanning from 10,500 to 150 cal yrs BP). Although it has been generally accepted that trends in fire, be they regional or local, are climatically driven (Francis, 1996), it is also true that small-scale variations in site characteristics are important to the dynamics of local-scale fire regimes around individual sites (Allen, 1982). Francis (1996) found that there are complex interactions between slope, elevation, and aspect characteristics that significantly effect local environmental conditions, and thus local fire regimes. The steep slopes that surround Lake WA01 result in an extremely small watershed for the study lake. Thus, the poor relationship between the local and regional fire regimes surrounding Lake WA01 is likely attributable to an extremely small macrocharcoal source area, illustrating the importance of considering the physical characteristics of study sites when interpreting local-scale paleoenvironmental records. The combination of high-resolution microcharcoal analysis with continuous macrocharcoal analysis is recommended in future studies to provide the most complete fire record possible for a given study area.

Climate

Bunbury & Gajewski (2009a) reconstruct mean July temperatures and total annual precipitation at Upper Fly Lake in the southwest Yukon for the last approximately 13,000 years. The period from 12,500 to 11,200 cal yrs BP corresponds to the timing of the Younger Dryas in the region, and to low reconstructed temperature and precipitation values. Decreased mean July temperatures and low total annual precipitation values persisted after the Younger Dryas in the region until ca. 10,000 cal yrs BP, when both temperature and precipitation increased dramatically. Similarly decreased total annual precipitation has been noted in the WA01 reconstructed precipitation record from the beginning of the sequence until ca. 9,900 cal yrs BP, when values increased to approximately modern levels. Anomalously high reconstructed mean July temperatures in the earliest portions of the WA01 record can be attributed to the influence a few of the modern sites selected as analogues at these depths (above). The influence of the same modern sites is also apparent at some of the other levels in the sediment when higher temperatures have been interpreted.

From ca. 10,000 cal yrs BP to the present, Bunbury & Gajewski (2009a) interpret a long-term cooling trend at Upper Fly Lake, as well as gradually increasing precipitation. The difference in temperature and precipitation values between the earlier (13-14°C and 330mm/yr at 10,000 cal yrs BP) and later (min. 12°C and 280mm/yr in the last 1,500 years) portions of the record is slight, however, and as has been mentioned previously, it is unclear whether this represents a true change to regional climate conditions. Mean July temperatures and total annual precipitation remained essentially constant (values averaging ca. 12.5°C and ca. 370-380 mm, respectively) over the course of the post-glacial period at Lake WA01, from ca. 9,900 cal yrs BP to the present day. Similarly, recent climate reconstructions from eastern Beringia (Viau *et al.*, 2008; Kurek *et al.*, 2009), as well as others from Dune (Bigelow, 1997), Farewell (Hu *et al.*, 1998), and Birch (Abbott *et al.*, 2000) Lakes in Alaska do not show any significant changes to mean July temperatures over the course of the Holocene in these regions, though Viau *et al.* (2008) does note a gradual decline in precipitation over the last 9,000 years that is contradictory to the results of the WA01 precipitation reconstruction, but which is in accord with the results of microcharcoal analysis (above). Gradual decreases in total annual precipitation in eastern Beringia over the last 9,000 years, which are noted by Viau *et al.* (2008) are thus interpreted to have been less pronounced in the southwest Yukon Territory than has been suggested for the eastern Beringian study sites, such that no significant change occurred in the vegetation of the study region. Slight decreases to the total annual precipitation in the southwest Yukon and Aishihik Basin over the course of the Holocene, while perhaps not pronounced enough to affect the vegetation, may, however, still have caused the regional fire regime of area to slowly intensify, which, as has previously been discussed, might account for progressively increasing regional fire frequency and/or size through time in the WA01 regional fire record.

Variations in sediment organic and carbonate content

The alternating pattern in the sediment loss-on-ignition from Lake WA01 is the most prominent "signal" that is visible in the record at the scale of hundreds to thousands of years. Major transitions from high sediment carbonate content to high sediment organic content and back again occurred with a period of approximately 1,000 years for the last ca. 6,000 years of the record. Some evidence of similar sudden changes to the sediment is also visible in the earliest portions of the core. High concentrations of mollusk shells often occurred in levels where high sediment carbonate content was recorded, however, the occurrence of high sediment carbonate content was not restricted only to levels with increased mollusk shells, which would tend to suggest that changes in mollusk abundance cannot explain all of the variability that is present in the carbonate record.

Studies by Levesque *et al.* (1994), Birks *et al.* (2000), Kaplan *et al.* (2002), Andresen *et al.* (2004), McKay *et al.* (2008), and Fortin & Gajewski (2009) note a positive relationship between the organic content of lake sediments and increased paleotemperatures interpreted from pollen and other proxy-climate indicators at sites in New Brunswick, Norway, Greenland, Alaska, and the Canadian Arctic. In these studies, the authors interpret increased sediment organic content in their cores as the result of warmer conditions around their study lakes, which caused increased catchment productivity, and thus an increase in organic material being deposited to the lake sediments. Brown *et al.* (2005) also suggest that decreased organic material and increased carbonate material in the sediment can be interpreted as an indicator of wet conditions at their study site in the Canadian prairies. Combined, the results of these analyses suggest that the WA01 loss-on-ignition record might provide a record of paleotemperatures or paleoprecipitation in the study region, however, at Lake WA01, no clear association can be seen between the sediment organic and carbonate content and reconstructed mean July temperature and total annual precipitation values based on pollen data. The climate reconstructions of Viau *et al.* (2008), Kurek *et al.* (2009), Bigelow (1997), Hu *et al.* (1998), and Abbott *et al.* (2000)

(above) also reveal no significant periodic changes to climate conditions that can be associated with the WA01 loss-on-ignition record.

A ca. 1,500-year climate oscillation is identified in studies from the North Atlantic by, for example McManus *et al.* (1999), Raymo *et al.* (1998), and Oppo *et al.* (1998). Holocene climatic variability is attributed in these cases to changes in ocean-circulation patterns and the production of icebergs in the North Atlantic Ocean, and comparable climate variability could occur in the Yukon due to atmospheric or oceanic teleconnections. Viau *et al.* (2002) finds evidence of millennial-scale climate (a ca. 1,100 year cycle) variability in a collection of North American pollen records. The authors identify major transitions in the North American climate at ca. 600, 1,650, 2,850, 4,030, 6,700, 8,100, and 10,190 cal yrs BP, and suggest that abrupt transitions between climatic regimes at these times might have been the result of the reorganization of the global ocean-atmosphere circulation system in response to some external forcing (e.g. Milankovitch cycles; Viau *et al.*, 2002). The timing of the climate transitions that Viau *et al.* (2002) identify, however, is not clearly relatable to changes in the sediment loss-on-ignition record from Lake WA01, nor are these transitions reflected in the WA01 vegetation, fire, or climate reconstructions, suggesting that their effects were not significant in the study region.

A notable similarity does, however, appear to exist between the WA01 sediment loss-on-ignition record and trends in $\partial^{18}O$ values from the Mount Logan (Fisher *et al.*, 2008) oxygen isotope record over the course of the Holocene (Figure 4.10). Times of increased carbonate content in the WA01 record (e.g. from 1,400 to 2,500, 3,200 to 4,200, and 5,200 to 6,200 cal yrs BP) tend to be associated with enriched $\partial^{18}O$ values in the Mount Logan isotope record (avg. –31.4, -31.8, and –30.6 for each of these periods, respectively). Conversely, periods of time when carbonate content was decreased (e.g. from the present to 1,400 cal yrs BP, 2,500 to 3,200 cal yrs BP, and 4,200 to 5,200 cal yrs BP) have tended to correspond to periods when ∂^{18}O in the Mount Logan record tended to be more depleted (avg. – 31.6, -32.2, and –32.2).

Few similarities were apparent between the WA01 loss-on-ignition record and the Eclipse ice core ∂^{18}O isotope record (Yalcin & Wake, 2001). Like the Mount Logan isotope record, the Eclipse icefield ∂^{18}O sequence originates in the St. Elias mountain range, however, the Eclipse ice core drilling site was at significantly lower elevation than that of the Logan, in an area of higher accumulation and more limited wind severity (Yalcin & Wake, 2001). As a result, the Eclipse ice core is valuable as a record of continental-scale events and patterns occurring at lower levels of the atmosphere (Yalcin & Wake, 2001), while the high altitude of the Mount Logan site results in it recording changes occurring at broader geographical scales.

Fisher *et al.* (2004) suggest that changes to the enrichment/depletion of the ∂^{18}O in the Mount Logan isotope record through time are related to periodic and sudden changes to the strength and position of the Aleutian Low (AL) in the North Pacific, as measured by the North Pacific Index (NPI). Anderson *et al.* (2005) suggest that when the AL is stronger or positioned further to the east, strong southerly winds lead to the enhancement of rainout on the coastal side of the Pacific Cordillera, and to the deposition of depleted ∂^{18}O in the rain shadow on the other side. The authors associate these conditions with a drier climate in the interior (Anderson *et al.*, 2005). Conversely, when the AL is weaker or further west, the ∂^{18}O flux is enriched and conditions are generally wetter on the lee side of the mountains. Thus, the positive association that has been observed between sediment carbonate content in the WA01 core and enriched ∂^{18}O values from the Mount Logan record might suggest that the alternating high carbonate and high organic states of the WA01 sediment loss-on-ignition record can be related to periods of wetter (higher sediment carbonate content, enriched $\partial^{18}O$) and drier (lower sediment carbonate content, depleted $\partial^{18}O$) conditions at the study site, although these changes were apparently not significant enough to have greatly influenced the composition of the surrounding vegetation or fire regime. It is conceivable that the extremely small size of the study lake might have made lake environment more susceptible to periodic slight changes in regional precipitation than the surrounding vegetation, or the regional and/or local fire regimes. This possibility would account for the periodic changes to the sediment loss-on-ignition, while accounting for the lack of such change in the pollen, fire, and reconstructed climate records. Small lakes are known to be more susceptible to the effects of environmental change than large lakes (Müller *et al.*, 1998). Previous paleoenvironmental studies on the Yukon and Alaska have also tended to have been conducted on significantly larger lakes than Lake WA01, which with their greater size would most likely be less susceptible to small changes in total annual precipitation. A similar proposition has also recently been made by Michelutti *et al.* (2006) to explain why the ecological response of several small ponds from Cape Herschel to recent climate warming in the Canadian Arctic was more pronounced than that of larger Rock Basin Lake on Ellesmere Island. Additional studies showing relationships between sediment loss-on-ignition and the climate variability caused by changes in the atmospheric circulation are required to confirm this potential explanation.

4.6 Summary and Conclusions

The earliest portion of the WA01 pollen record was characterized by the establishment of open birch-shrub tundra at the study site. *Picea glauca* established ca.

9,900 cal yrs BP and has since remained dominant on the landscape. The boreal forest has remained similar in structure and composition to the modern forest of the region since its development. Periodic slight decreases in the abundance of *Picea glauca* pollen after 9,900 cal yrs BP corresponded to increases in the abundance of deciduous tree, herb, and shrub pollen taxa such as *Betula*, *Salix*, Poaceae, *Alnus crispa*, Cyperaceae, and *Juniperus*. The early date of spruce establishment at the study site is in agreement with the potential route of post-glacial spruce migration that has been proposed by Lacourse & Gajewski (2000). The later dates of spruce establishment that have been noted at many sites to the west of the study lake would also tend to support this interpretation.

The climate of the study region was characterized by low total annual precipitation until ca. 9,900 cal yrs BP. Anomalously high reconstructed mean July temperatures in the earliest portions of the WA01 record can be attributed to the influence of a few of the modern sites selected as analogues at those levels. From ca. 9,900 cal yrs BP to the present day, mean July temperatures and total annual precipitation at the study site remained essentially constant at values of ca. 12.5°C and ca. 370-380 mm, respectively. A gradual decline in total annual precipitation in eastern Beringia over the last ca. 9,000 years, which has been interpreted by Viau *et al.* (2008), is not reconstructed using the pollen data from Lake WA01, though some evidence for a slight decline in total annual precipitation can be interpreted from the record of regional-scale fire which has been developed for the study lake.

The regional-scale fire regime surrounding the study site increased gradually in intensity over the course of the Holocene. This is interpreted to be as a result of progressively decreasing precipitation in the region over the last ca. 9,000 years, as has been suggested by Viau *et al.* (2008), although this trend is not visible in the WA01 pollen record. Thus it is suggested that the change in precipitation noted by Viau *et al.* (2008), while being great enough to cause a change to the regional fire regime surrounding the study site, was not significant enough in the study region to have had any effect on the composition of the regional vegetation. That no notable change to the vegetation would have occurred as a result of decreasing precipitation over the course of the Holocene can attributed to the already arid conditions of the study region, which would encourage the vegetation to be relatively well drought-adapted.

The WA01 macrocharcoal record indicates that local fires in the area immediately surrounding the study lake have decreased gradually in frequency and/or size over the course of the Holocene. Early in the record, the mean fire interval in the area immediately surrounding the lake was approximately 280 years, however, in the latter ca. 6,000 years of the WA01 record, the MFI at Lake WA01 increased significantly to approximately 720 yrs. While the possible impacts of sampling resolution, depositional processes, and/or climatic changes cannot be completely dismissed, the exact cause of the gradual decrease in macrocharcoal influx over the length of the WA01 core remains unclear.

The alternating pattern in the sediment loss-on-ignition from Lake WA01 is the most prominent "signal" that is visible in the record at the scale of hundreds to thousands of years, and is notably similar to trends in $\partial^{18}O$ values from the Mount Logan (Fisher *et al.*, 2008) oxygen isotope record. Based on a positive association between sediment carbonate content and enriched $\partial^{18}O$ values from the Mount Logan record, it is proposed that periods of increased and decreased sediment carbonate content in the WA01 core are indicative of wetter and drier conditions at the study site. That no significant corresponding changes to the surrounding vegetation community, to the regional and/or local fire regimes, or to the regional climate can be observed is attributed to the extremely small size of the study lake, which conceivably may have made the lake environment more susceptible to periodic slight changes to climatic conditions than the surrounding vegetation, or the regional and/or local fire regimes. Additional studies showing a relationship between sediment loss-on-ignition and the atmospheric circulation are required to confirm this potential explanation, and more study of the responsiveness of small lakes to environmental change when compared to larger lakes is needed to develop our understanding of the particular sensitivity of small lakes to climate change.

Acknowledgements

This research was supported by a National Sciences and Engineering Research Council (NSERC) grant to K. Gajewski, and by an NSERC scholarship, and Northern Scientific Training Program (NSTP) grant to R. Ravindra. Thanks to the Arctic Institute of North America and to Andy and Carol Williams, Sian Williams and Lance Goodwin for logistical support in the field. Thanks also to Matthew Peros, Luke Copland, Phil Mosher, Sarah Boteler and Joey Taylor for help in the field. Thanks to all of the members of the LPC for help in the laboratory and with analysis.

References

Abbott, M.B., Finney, B.P., Edwards, M.E., & Kelts, K.R. 2000. Lake-level reconstructions and paleohydrology of Birch Lake, Central Alaska, based on seismic reflection profiles and core transects. *Quaternary Research* 53: 154-166.

Aber, J.D. & Melillo, J.M. 2001. *Terrestrial Ecosystems.* Harcourt Academic Press, San Diego, USA.

Allen, H.D. 1982. *Dendrochronological studies on the Slims River Valley, Yukon Territory.* M.Sc. Thesis. University of Calgary. 179 pp.

Anderson, L., Abbott, M.B., Finney, B.P., & Burns, S.J. 2005. Regional atmospheric circulation change in the North Pacific during the Holocene inferred from lacustrine carbonate oxygen isotopes, Yukon Territory, Canada. *Quaternary Research* 64: 21-35.

Anderson, L., Hu, F.S., Nelson, D.M., Petit, R.J., & Paige, K.N. 2006a. Ice-age endurance: DNA evidence of a white spruce refugium in Alaska. *Proceedings of the National Academy of Sciences* 103(33): 12447-12450.

Andresen, C.S., Bjorck, S., Rundgren, M., Conley, D.J., & Jessen, C. 2004. Holocene climate changes in southern Greenland: evidence from lake sediments. *Journal of Quaternary Sciences* 19: 783-795.

Bennett, K.D. & Willis, K.J. 2001. Pollen. In, J.P. Smol, H.J.B. Birks, & W.M. Last (Eds.), *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 5-32.

Bigelow, N.H. 1997. *Late-Quaternary vegetation and climate in Central Alaska.* PhD Thesis. University of Alaska.

Birks, H.H., Battarbee, R.W., & Birks, H.J.B. 2000. The development of the aquatic ecosystem at Krakenes Lake, western Norway, during the late glacial and early Holocene–a synthesis. *Journal of Paleolimnology* 23: 91–114.

Birks, H.J.B. 1980. Modern pollen assemblages and vegetation history of the moraines of the Klutlan glacier and its surroundings, Yukon Territory, Canada. *Quaternary Research* 14: 101-129.

Bourgeois, J.C. & Guerts, M.-A. 1983. Palynologie et morphogenese recents dans le basin du Grizzly Creek (Territoire du Yukon). *Canadian Journal of Earth Sciences* 20: 1,543-1,553.

Brown, K.J., Clark, J.S., Grimm, E.C., Donovan, J.J., Mueller, P.G., Hansen, B.C.S., Stefanova, I., & Wright, Jr., H.E. 2005. Fire cycles in North American interior grasslands and their relation to prairie drought. *Proceedings of the National Academy of Sciences* 102: 8865-8870.

Brubaker, L.B., Anderson, P.M., Edwards, M.E., & Lozhkin, A.V. 2005. Beringia as a glacial refugium for boreal trees and shrubs: new perspectives from mapped pollen data. *Journal of Biogeography* 35(5): 833-848.

Bunbury, J. & Gajewski, K. 2009a. Quantitative analysis of freshwater ostracode assemblages in southwestern Yukon Territory, Canada. *Hydrobiologia* 545(1): 117-128.

Carlson, L.J. & Finney, B.P. 2004. A 13,000-year history of vegetation at Jan Lake, east central Alaska. *The Holocene* 14: 818-827.

Clague, J.J., Evans, S.G., Rampton, V.N., & Woodsworth, G.J. 1995. Improved age estimates for the White River and Bridge River tephras, Western Canada. *Canadian Journal of Earth Sciences* 32: 1,172-1,179.

Colinvaux, P. 1964. The environment of the Bering Land Bridge. *Ecological Monographs* 34(3): 297-329.

Cwynar, L.C. & Ritchie, J.C. 1980. Arctic steppe-tundra: a Yukon perspective. *Science* 208: 1,375-1,377.

Cwynar, L.C. & Spear, R.W. 1991. Reversion of forest to tundra in the central Yukon. *Ecology* 72: 202-212.

Cwynar, L.C. & Spear, R.W. 1995. Paleovegetation and paleoclimatic changes in the Yukon at 6ka BP. *Geographie physique et quaternaire* 49: 29-35.

Cwynar, L.C. 1982. Late quaternary vegetation history from Hanging Lake, northern Yukon. *Ecological Monographs* 52: 1-24.

Cwynar, L.C. 1988. Late quaternary vegetation history of Kettlehole Pond, southwestern Yukon. *Canadian Journal of Forest Research* 18: 1,270-1,279.

Dean, Jr., 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.

Faegri, K. & Iverson, J. 1989. *Textbook of Pollen Analysis*. John Wiley and Sons, Toronto.

Fisher, D.A., Wake, C., Kreutz, K., Yalcin, K., Steig, E., Mayewski, P., Anderson, L., Zheng, J., Rupper, S., Zdanowicz, C., Demuth, M, Waszkiewicz, M., Dahl-Jensen, D., Goto-Azuma, K., Bourgeois, J.B., Koerner, R.M., Sekerka, J., Osterberg, E., Abbot, M.B., Finney, B.P., & Burns, S.J. 2004. Stable isotope records from Mount Logan, Eclipse ice cores and nearby Jellybean Lake. Water cycle of the North Pacific over 2000 years and over five vertical kilometers: sudden shifts and tropical connections. *Géographie physique et Quaternaire* 58: 337-352.

Fisher, D., Dyke, A., Dahl-Jensen, D., Demuth, M., Zdanowicz, C,. Bourgeois, J., Koerner, R., Mayewski, P., Wake, C., Kreutz, K., Steig, E., Zheng, J., Yalcin, K., Goto-Azuma, K., Luckman, B. & Rupper, S. 2008. The Mt Logan Holocene-latw Wisconsinan isotope record: tropical Pacific-Yukon connections. *The Holocene* 18(5): 667-677.

Fortin, M.-C. & Gajewski, K. 2009. Assessing the use of sediment organic, carbonate and biogenic silica content as indicators of environmental conditions in Arctic lakes. *Polar Biology* 32(7): 985-998.

Francis, S.R. 1996. *Linking landscape pattern and forest disturbance: Fire history of the Shakwak Trench, southwest Yukon Territory*. M.Sc. Thesis. University of Alberta. 130 pp.

Fulton, R.J. 1995. Surficial materials of Canada. Geological Survey of Canada Map 1880A, Scale 1:5,000,000.

Hu, F., Brubaker, L.B., & Anderson, P.A. 1996. Boreal ecosystem development in the northwestern Alaska Range since 11,000 yr BP. *Quaternary Research* 45: 188-201.

Hu, F., Ito, E., Brubaker, B., & Anderson, P.M. 1998. Ostracode geochemical records of Holocene climate change and implication for vegetation response in the northwestern Alaska range. *Quaternary Research* 49: 89-95.

Hu, F., Brubaker, L.B., Gavin, D.G., Higuera, P.E., Lynch, J.A., Rupp, T.S., & Tinner, W. 2006. How climate and vegetation influence the fire regime of the Alaskan boreal biome: The Holocene perspective. *Mitigation and Adaptation Strategies for Global Change* 11: 829-846.

IPCC Working Group II. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. IPCC Secretariat c/o World Meteorological Organization, 7 bis Avenue de la Paix, C.P. 2300, CH - 1211 Geneva 2, Switzerland.

Kaplan, M.R., Wolfe, A.P., & Miller, G.H. 2002. Holocene environmental variability in Southern Greenland inferred from lake sediments. *Quaternary Research* 58: 149-159.

Kapp, R. 2000. *How to know Pollen and Spores*. American Association of Stratigraphic Palynologists Foundation publication.

Keenan, T.J. & Cwynar, L.C. 1982. Late quaternary history of black spruce and grasslands in southwest Yukon Territory. *Canadian Journal of Botany* 70: 1,336-1,345.

Kurek, J., Cwynar, L.C., Ager, T.A., Abbott, M.B., & Edwards, M.E. 2009. Late Quaternary paleoclimate of western Alaska inferred from fossil chironomids and its relation to vegetation histories. *Quaternary Science Reviews* 28(9-10): 799-811.

Lacourse, T. & Gajewski, K. 2000. Late quaternary vegetation history of Sulphur Lake, southwest Yukon Territory, Canada. *Arctic* 53: 27-35.

Levesque, A.J., Cwynar, L.C., & Walker, I.R. 1994. A multiproxy investigation of late-glacial climate and vegetation change at Pine Ridge Pond, southwest New Brunswick, Canada. *Quaternary Research* 42: 316–327.

Lynch, J., Clark, J.S., Bigelow, N.H., Edwards, M.E., & Finney, B.P. 2003. Geographic and temporal variations in fire history in boreal ecosystems of Alaska. *Journal of Geophysical Research* 108(D1): 8,152, doi: 10.1029/2001JD000332.

Lynch, J., Hollis, J., & Hu, F. 2004. Climatic and landscape controls of the boreal forest fire regime: Holocene records from Alaska. *Journal of Ecology* 92: 477-489.

MacDonald, G.M., Beukens, R.P., & Kieser, W.E. 1991. Radiocarbon Dating of Limnic Sediments: A Comparative Analysis and Discussion. *Ecology* 72: 1,150-1,155.

McAndrews, J.H., Berti, A.A., & Norris, G. 1973. *Key to the Quaternary pollen and spores of the Great Lakes Region*. Royal Ontario Museum, Miscellaneous publication.

McCoy, V.M. & Burn, C.R. 2005. Potential alteration by climate change of the forest-fire regime in the boreal forest of central Yukon Territory. *Arctic* 58: 276-285.

McKay, N.P., Kaufman, D.S., & Michelutti, N. 2008. Biogenic silica concentration as a high resolution, quantitative temperature proxy at Hallet Lake, south-central Alaska. *Geophysical Research Letters* 35: L05709.

McManus, J., Oppo, D.W., & Cullen, J. 1999. A 0.5 million-year record of millennial-scale climate variability in the North Atlantic. *Science* 283: 971-974.

Michelutti, N., Douglas, M., Wolfe, A., & Smol, J.P. 2008. Heightened sensitivity of a poorly buffered high arctic lake to late-Holocene climatic change. *Quaternary Research* 65(3): 421-430.

Minckley T.A., Whitlock, C., & Bartlein, P.J. 2007. Vegetation, fire, and climate history of the northwestern Great Basin during the last 14,000 years. *Quaternary Science Reviews* 26: 2,167–2,184.

Moore, P.D. & Webb, J.A. 1978. *An illustrated guide to pollen analysis*. Wiley, New York, USA.

Müller, B., Lötter, A.F., Sturm, M., & Ammann, A. 1998. Influence of catchment quality and altitude on the water and sediment composition of 68 small lakes in Central Europe. *Aquatic Sciences* 60: 316-337.

National Atlas Information Service. 1995. Canada, Permafrost. The National Atlas of Canada Map (5th ed) MCR 4177, Scale 1:7,500,000.

Oppo, D.W., McManus, J., & Cullen, J. 1998. Abrupt climate evens 500000 to 340000 years ago: Evidence from subpolar North Atlantic sediments. *Science* 279: 1335-1338.

Pisaric, M.F.J., MacDonald, G.M., Velichko, A.A., & Cwynar, L.C. 2001. The lateglacial and post-glacial vegetation history of the northwestern limits of Beringia, based on pollen, stomate, and tree stump evidence. *Quaternary Science Reviews* 20: 235-245.

Rampton, V. 1971. Late Pleistocene glaciation of the Snag-Klutlan area, Yukon Territory. *Arctic* 24: 277-300.

Raymo, M.E., Ganley, K., Carter, S., Oppo, D.W., & McManus, J. 1998. Millennial-scale climate instability during the early Pleistocene epoch. *Nature* 392: 699-702.

Reimer, P., Baillie, M., Bard, E., Bayliss, A., Beck, J., Bertrand, C., Blackwell, P., Buck, C., Burr, G., Cutler, K., Damons, P., Edwards, R., Fairbanks, R., Friedrich, M., Guilderson, T., Hogg, A., Hughen, K., Kromer, B., McCormac, G., Manning, S., Ramsey, C., Reimer, R., Remmele, S., Southon, J., Stuiver, M., Talamo, S., Taylor, F., van der Plicht, J., & Weyhenmeyer, C. 2004. INTCAL04 Terrestrial radiocarbon age calibration, 0-26 cal kyr BP. *Radiocarbon* 46: 1,029-1,058.

Ritchie, J.C. 1982. The modern and late Quaternary vegetation of the Doll Creek area, north Yukon, Canada. *New Phytologist* 90: 563-603.

Robinson, S.D. 2001. Extending the late Holocene White River Ash distribution, northwestern Canada. *Arctic* 54: 157-161.

Sawada, M., Viau, A.E., Vettoretti, G., Peltier, W.R., & Gajewski, K. 2004. Comparison of North American pollen-based temperature and global lake status with CCCma AGCM2 output at 6ka. *Quaternary Science Reviews* 23: 225-244.

Sawada, M. 2006. An open source implementation of the modern analogue technique (MAT) within the R computing environment. *Computers and Geosciences* 32: 818-833.

Shaw, P. 2003. *Multivariate Statistics for the Environmental Sciences*. Arnold Publishers, London.

Smol, J.P. 2002. *Pollution of lakes and rivers: a paleonvironmental perspective*. Oxford Press Inc., New York, USA.

Stuart, G.S.L., Helmer, J.W., & Hills, L.V. 1989. The Holocene paleoecology of Jenny Lake area, southwest Yukon, and its implications for prehistory. *Arctic* 42: 347-353.

Szeicz, J.M. & MacDonald, G.M. 2001. Montane climate and vegetation dynamics in easternmost Beringia during the late Quaternary. *Quaternary Science Reviews* 20: 247-257.

Tinner, W., Hu, F., Beer, R., Kaltenrider, P., Scheurer, B., & Krahenbuhl, U. 2006. Post-glacial vegetation and fire history: pollen, plant macrofossil, and charcoal records from two Alaskan lakes. *Vegetation History and Archaeobotany* 15: 279-293.

Viau, A., Gajewski, K., Fines, P., Atkinson, D.E., & Sawada, M. 2002. Widespread evidence of 1500 yr climate climate variability in North America during the past 14000 yr. *Geology* 30(5): 455-458.

Viau, A.E., Gajewski, K., Sawada, M.C., & Fines, P. 2006. Millennial-scale temperature variations in North America during the Holocene. *Journal of Geophysical Research-Atmosphere* 111: D09102, DOI: 10.1029/2005JD006031.

Viau, A.E., Gajewski, K., Sawada, M.C., & Bunbury, J. 2008. Low-and high frequency climate variability in Eastern Beringia during the past 25,000 years. *Canadian Journal of Earth Sciences* 45: 1435-1453. DOI: 10.1139/E08-036.

Wang, X.-C. & Guerts, M.-A. 1991a. Late Quaternary pollen records and vegetation history of the southwest Yukon Territory: A review. *Geographie physique et quaternaire* 45: 175-193.

Wang, X.-C. & Guerts, M.-A. 1991b. Post-glacial vegetation history of the Ittlemit lake basin, southwest Yukon Territory. *Arctic* 44: 23-30.

Wang, X.-C. 1989. *Pot-glacial vegetation history of the Aishihik basin and its vicinity, southwest Yukon Territory: A palynologial perspective*. PhD Thesis. University of Ottawa. 544pp.

Whitlock, C. & Larsen, C. 2001. Charcoal as a fire proxy. In, J.P. Smol, H.J.B. Birks, & W.M. Last (Eds.), *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 75-97.

Whitmore, J., Gajewski, K., Sawada, M., Williams, J.W., Shuman, B., Bartlein, P.J., Minckley, T., Viau, A.E., Webb III, T., Shafer, S., Anderson, P., & Brubaker, L. 2005. Modern pollen data from North America and Greenland for multi-scale paleoenvironmental applications. *Quaternary Science Reviews* 24: 1,828-1,848.

Whittmire, C.M. 2000. *Vegetative and fire history of the area surrounding Keyhole Pond, Yukon Territory*. M.Sc. Thesis. University of Regina.

Willard, D.A., Bernhardt, C.E., Brooks, G.R., Cronin, T.M., Edgar, T., & Larson, R. 2007. Deglacial climate variability in central Florida, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology* 251: 366-382.

Williams, J. & Shuman, B. 2008. Obtaining accurate and precise environmental reconstructions from the modern analog technique and North American surface pollen dataset. *Quaternary Science Reviews 27*(7-8): 669-687.

Wright, Jr., H.E. 1967. A square-rod piston sampler for lake sediments. *Journal of Sedimentary Petrology* 37: 957-976.

Yalcin, K. & Wake, C.P. 2001. Anthropogenic signals recorded in an ice core from Eclipse Icefield, Yukon Territory, Canada. *Geophysical Research Letters* 28(23): 4487-4490.

Zabenskie, S., Peros, M., & Gajewski, K. 2006. The use of heavy-liquid in the separation of pollen from Arctic lake sediments. *Canadian Association of Palynologists Newsletter* 29: 5-7.

Zabenskie, S. & Gajewski, K. 2007. Post-glacial climatic change on Boothia Peninsula, Nunavut, Canada. *Quaternary Research* 68: 261-270.

Chapter 5 – Summary

Paleocological studies based on the analysis of lake sediments offer the potential for high resolution and well-dated records of past environmental conditions. A 2.7 m sediment core raised from Lake WA01 (unofficial name, 61°14'41"N, 136°55'35" W, 1000 m.a.s.l.) in the Aishihik region of the southwest Yukon Territory documents the post-glacial vegetation, fire, and climate history of the region surrounding the study site. Radiocarbon and ^{210}Pb dating of the sediment provides a reliable chronology with no age reversals and an approximately linear age-depth sequence. Deglaciation occurred at the study site ca. 10,500 cal yrs BP.

The earliest portion of the WA01 pollen record was characterized by the presence of high proportions of *Betula* pollen, and also by the presence of *Alnus crispa*, *Salix*, Poaceae, and Cyperaceae pollen grains, indicating the establishment of a birch-shrub tundra at the study site soon after deglaciation. *Picea glauca* established ca. 9,900 cal yrs BP and has since remained dominant on the landscape. The boreal forest has remained similar in structure and composition to the modern forest of the region since its development. Periodic slight decreases in the abundance of *Picea glauca* pollen after 9,900 cal yrs BP corresponded to increases in the abundance of deciduous tree, herb, and shrub pollen taxa such as *Betula*, *Salix*, Poaceae, *Alnus crispa*, Cyperaceae, and *Juniperus*, however these variations were not sufficiently great at any time to cause *Picea glauca* to be replaced as the dominant taxon in the vegetation.

The timing and pattern of spruce migration into the southwest Yukon has previously been investigated, but remains unclear. The date of spruce establishment at Lake WA01 is somewhat earlier than in many other regions of the southwest Yukon. This early date of spruce establishment at the study site is in agreement with the potential route of migration that has been proposed by Lacourse & Gajewski (2000). Its is possible that following deglaciation, *Picea glauca* migrated northward into the Yukon Territory from northern British Columbia to the Liard River, and from there into the Tintina Trench, and then south and westward into the Aishihik Basin and Shakwak Trench further west. By this path, *Picea glauca* would have arrived at the study site at a relatively early date, and would then have continued to establish in the remainder of the Aishihik Basin and eventually in the Shakwak Trench. The later dates of spruce establishment that have been noted at many sites to the west of the study lake would also tend to support this interpretation.

The climate of the study region was characterized by low total annual precipitation until ca. 9,900 cal yrs BP. Anomalously high reconstructed mean July temperatures in the earliest portions of the WA01 record can be attributed to non-analogue conditions leading to the selection of inappropriate modern analogue sites. From ca. 9,900 cal yrs BP to the present day, mean July temperatures and total annual precipitation at the study site remained essentially constant at values ca. 12.5°C and ca. 370-380 mm, respectively. A gradual decline in total annual precipitation in eastern Beringia over the last ca. 9,000 years, which has been interpreted by Viau *et al.* (2008), is not captured in the climate reconstructions from Lake WA01, though some evidence for a slight decline in total annual precipitation can be interpreted from the record of regional-scale fire which has been developed for the study lake.

The regional-scale fire regime surrounding the study site increased gradually in intensity over the course of the Holocene. This is interpreted to be as a result of progressively decreasing precipitation in the region over the last ca. 9,000 years, as has been suggested in the study by Viau *et al.* (2008), but which is not captured in the pollen record, or in the climate reconstructions that have been presented in this study. It is thus suggested that the change in precipitation noted by Viau *et al.* (2008), while being great enough to cause a change to the regional fire regime surrounding the study site, was not significant enough in the study region to have had any effect on the composition of the regional vegetation. Thus, gradually declining total annual precipitation in the study region would not appear in pollen-based climate reconstructions from the study lake, as has been noted in the record of total annual precipitation that has been developed for Lake WA01. That no notable change to the vegetation would have occurred as a result of decreasing precipitation over the course of the Holocene can attributed to the already arid conditions of the study region, which would encourage the vegetation to be relatively well drought-adapted.

Few similarities have existed between the regional and local fire regimes surrounding Lake WA01 over the course of its history. This is interpreted to be the result of the study lake's extremely small watershed, which would tend to cause the macrocharcoal signal to be very local in nature. The use of extreme caution when interpreting record of local fire is thus suggested. The combination of high-resolution microcharcoal analysis with continuous macrocharcoal analysis is recommended in future studies to provide the most complete fire record possible for a given study area.

The WA01 macrocharcoal record indicates that local fires in the area immediately surrounding the study lake have decreased gradually in frequency and/or size over the course of the Holocene. Early in the record, the mean fire interval in the area immediately surrounding the lake was approximately 280 years. This compares well with the results of other macrocharcoal studies from northwest North America, where MFIs have normally ranged between 200 and 400 years, however, in the latter ca. 6,000 years of the WA01 record, the MFI at Lake WA01 increased significantly to approximately 720 yrs. While the possible impacts of sampling resolution, depositional processes, and/or climatic changes cannot be completely dismissed, the exact cause of the gradual decrease in macrocharcoal influx over the length of the WA01 core remains unclear.

The alternating pattern in the sediment loss-on-ignition from Lake WA01 is the most prominent "signal" that is visible in the record at the scale of hundreds to thousands of years, and is notably similar to trends in $\partial^{18}O$ values from the Mount Logan (Fisher *et al.*, 2008) oxygen isotope record. Major transitions from high sediment carbonate content to high sediment organic content and back again occurred with a period of approximately 1,000 years for the last ca. 6,000 years of the WA01 sequence. Times of increased carbonate content in the WA01 record tended to be associated with enriched $\partial^{18}O$ values in the Mount Logan record, while periods of time when carbonate content was decreased tended to correspond to periods when $\partial^{18}O$ in the Mount Logan record were more depleted. Fisher *et al.* (2004) has suggested that changes to the enrichment/depletion of the $\partial^{18}O$ in the Mount Logan isotope record through time are related to periodic and sudden changes to the strength and position of the Aleutian Low (AL) in the North Pacific. Based on a positive association between sediment carbonate content and enriched $\partial^{18}O$ values from the Mount Logan record, it is proposed that periods of increased and decreased sediment carbonate content in the WA01 core are indicative of wetter and drier conditions at the study site. That no significant corresponding changes to the surrounding vegetation community, to the regional and/or local fire regimes, or to the regional climate can be observed, is attributed to the extremely small size of the study lake, which conceivably may have made the lake environment more susceptible to periodic slight changes to climatic conditions than the surrounding vegetation, or the regional and/or local fire regimes. However, additional studies showing a relationship between sediment loss-on-ignition and the AL are required to confirm this potential explanation, and more study of the responsiveness of small lakes to environmental change when compared to larger lakes is needed to develop our understanding of the particular sensitivity of small lakes to climate change.

References

Abbott, M.B., Finney, B.P., Edwards, M.E., & Kelts, K.R. 2000. Lake-level reconstructions and paleohydrology of Birch Lake, Central Alaska, based on seismic reflection profiles and core transects. *Quaternary Research* 53: 154-166.

Aber, J.D. & Melillo, J.M. 2001. *Terrestrial Ecosystems*. Harcourt Academic Press, San Diego, USA.

Allen, H.D. 1982. *Dendrochronological studies on the Slims River Valley, Yukon Territory*. M.Sc. Thesis. University of Calgary. 179 pp.

Anderson, L., Abbott, M.B., Finney, B.P., & Burns, S.J. 2005. Regional atmospheric circulation change in the North Pacific during the Holocene inferred from lacustrine carbonate oxygen isotopes, Yukon Territory, Canada. *Quaternary Research* 64: 21-35.

Anderson, L., Hu, F.S., Nelson, D.M., Petit, R.J., & Paige, K.N. 2006a. Ice-age endurance: DNA evidence of a white spruce refugium in Alaska. *Proceedings of the National Academy of Sciences* 103(33): 12447-12450.

Anderson, R.S., Hallett, D.J., Berg, E., Jass, R.S., Toney, J.L., de Fontaine, C.S., & DeVolder, A. 2006b. Holocene development of boreal forests and fire regimes on the Kenai lowlands of Alaska. *The Holocene* 16: 791-803.

Andresen, C.S., Bjorck, S., Rundgren, M., Conley, D.J., & Jessen, C. 2004. Holocene climate changes in southern Greenland: evidence from lake sediments. *Journal of Quaternary Sciences* 19: 783-795.

Appleby, P.G. 2001. Chronostratigraphic Techniques in Recent Sediments. In, J.P. Smol & W.M. Last (Eds.), *Tracking Environmental Change Using Lake Sediments. Volume 1: Basin Analysis, Coring, and Chronological Techniques*. Kluwer Academic Publishers, Dordtrecht, The Netherlands. pp. 171-204.

Bennett, K.D. & Willis, K.J. 2001. Pollen. In, J.P. Smol, H.J.B. Birks, & W.M. Last (Eds.), *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 5-32.

Bigelow, N.H. 1997. *Late-Quaternary vegetation and climate in Central Alaska*. PhD Thesis. University of Alaska.

Birks, H.H., Battarbee, R.W., & Birks, H.J.B. 2000. The development of the aquatic ecosystem at Krakenes Lake, western Norway, during the late glacial and early Holocene–a synthesis. *Journal of Paleolimnology* 23: 91–114.

Birks, H.J.B. & Birks, H.H. 1980. *Quaternary Palaeoecology*. Edward Arnold, London, United Kingdom.
Birks, H.H. & Birks, H.J.B. 2006. Multi-proxy studies in paleolimnology. *Vegetation History and Archaeobotany* 15: 235-251.

Birks, H.J.B. 1980. Modern pollen assemblages and vegetation history of the moraines of the Klutlan glacier and its surroundings, Yukon Territory, Canada. *Quaternary Research* 14: 101-129.

Bourgeois, J.C. & Guerts, M.-A. 1983. Palynologie et morphogenese recents dans le basin du Grizzly Creek (Territoire du Yukon). *Canadian Journal of Earth Sciences* 20: 1,543-1,553.

Brown, K.J., Clark, J.S., Grimm, E.C., Donovan, J.J., Mueller, P.G., Hansen, B.C.S., Stefanova, I., & Wright, Jr., H.E. 2005. Fire cycles in North American interior grasslands and their relation to prairie drought. *Proceedings of the National Academy of Sciences* 102: 8865-8870.

Brubaker, L.B., Anderson, P.M., Edwards, M.E., & Lozhkin, A.V. 2005. Beringia as a glacial refugium for boreal trees and shrubs: new perspectives from mapped pollen data. *Journal of Biogeography* 35(5): 833-848.

Bunbury, J. & Gajewski, K. 2009a. Quantitative analysis of freshwater ostracode assemblages in southwestern Yukon Territory, Canada. *Hydrobiologia* 545(1): 117-128.

Bunbury, J. & Gajewski, K. 2009b. Variations in the depth and thickness of the White River Ash in lakes of the Southwest Yukon. In L.H. Weston, L.R. Blackburn, & L.L. Lewis (eds.). *Yukon Exploration and Geology*. Yukon Geological Survey. pp. 77-84.

Carlson, L.J. & Finney, B.P. 2004. A 13,000-year history of vegetation at Jan Lake, east central Alaska. *The Holocene* 14: 818-827.

Clague, J.J., Evans, S.G., Rampton, V.N., & Woodsworth, G.J. 1995. Improved age estimates for the White River and Bridge River tephras, Western Canada. *Canadian Journal of Earth Sciences* 32: 1,172-1,179.

Cogbill, C.V. 1985. Dynamics of the boreal forests of the Laurentian Highlands, Canada. *Canadian Journal of Forest Research* 15: 252–261.

Cohen, A.S. 2003. *Paleolimnology: the history and evolution of lake systems*. Oxford University Press, Toronto.

Colinvaux, P. 1964. The environment of the Bering Land Bridge. *Ecological Monographs* 34(3): 297-329.

Cwynar, L.C. & Ritchie J.C. 1980. Arctic steppe-tundra: a Yukon perspective. *Science* 208: 1,375-1,377.

Cwynar, L.C. & Spear, R.W. 1991. Reversion of forest to tundra in the central Yukon. *Ecology* 72: 202-212.

Cwynar, L.C. & Spear, R.W. 1995. Paleovegetation and paleoclimatic changes in the Yukon at 6ka BP. *Geographie physique et quaternaire* 49: 29-35.

Cwynar, L.C. 1982. Late quaternary vegetation history from Hanging Lake, northern Yukon. *Ecological Monographs* 52: 1-24.

Cwynar, L.C. 1988. Late quaternary vegetation history of Kettlehole Pond, southwestern Yukon. *Canadian Journal of Forest Research* 18: 1,270-1,279.

Dean, Jr., 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.

Faegri, K. & Iverson, J. 1989. *Textbook of Pollen Analysis*. John Wiley and Sons, Toronto.

Fisher, D.A., Wake, C., Kreutz, K., Yalcin, K., Steig, E., Mayewski, P., Anderson, L., Zheng, J., Rupper, S., Zdanowicz, C., Demuth, M, Waszkiewicz, M., Dahl-Jensen, D., Goto-Azuma, K., Bourgeois, J.B., Koerner, R.M., Sekerka, J., Osterberg, E., Abbot, M.B., Finney, B.P., & Burns, S.J. 2004. Stable isotope records from Mount Logan, Eclipse ice cores and nearby Jellybean Lake. Water cycle of the North Pacific over 2000 years and over five vertical kilometers: sudden shifts and tropical connections. *Géographie physique et Quaternaire* 58: 337-352.

Fisher, D., Dyke, A., Dahl-Jensen, D., Demuth, M., Zdanowicz, C,. Bourgeois, J., Koerner, R., Mayewski, P., Wake, C., Kreutz, K., Steig, E., Zheng, J., Yalcin, K., Goto-Azuma, K., Luckman, B. & Rupper, S. 2008. The Mt Logan Holocene-latw Wisconsinan isotope record: tropical Pacific-Yukon connections. *The Holocene* 18(5): 667-677.

Fortin, M.-C. & Gajewski, K. 2009. Assessing the use of sediment organic, carbonate and biogenic silica content as indicators of environmental conditions in Arctic lakes. *Polar Biology* 32(7): 985-998.

Francis, S.R. 1996. *Linking landscape pattern and forest disturbance: Fire history of the Shakwak Trench, southwest Yukon Territory*. M.Sc. Thesis. University of Alberta. 130 pp.

Fulton, R.J. 1995. Surficial materials of Canada. Geological Survey of Canada Map 1880A, Scale 1:5,000,000.

Gajewski, K., Garneau, M., & Bourgeois, J. 1995. Paleoenvironments of the Canadian High Arctic Derived from Pollen and Plant Macrofossils: Problems and Potentials. *Quaternary Science Reviews* 14: 609-625.

Gajewski, K. 1995. Modern and Holocene pollen accumulation in some small Arctic lakes from Somerset Island, N.W.T., Canada. *Quaternary Research* 44: 228-236.

Galipeau, C., Kneeshaw, D., & Bergeron, Y. 1997. White spruce and balsam fir colonization of a site in the southeastern boreal forest as observed 68 years after fire. *Canadian Journal of Forest Research* 27: 139–147.

Heiri, O., Lotter, A., & Lemcke, G. 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility of results. *Journal of Paleolimnology* 25: 101-110.

Hicks, S. & Hyvarinen, H. 1999. Pollen influx values measured in different sedimentary environments and their paleoecological implications. *Grana* 38: 228-242.

Holdsworth, G., Higuchi, K., Zielinski, G.A., Mayewski, P.A., Wahlen, M., Deck, B., Chylek, P., Johnson, B., & Damiano, P. 1996. Historical biomass burning: Late 19th century pioneer agriculture revolution in northern hemisphere ice core data and its atmospheric interpretation. *Journal of Geophysical Research* 101: 23,317-23,334.

Hu, F., Brubaker, L.B., & Anderson, P.A. 1996. Boreal ecosystem development in the northwestern Alaska Range since 11,000 yr BP. *Quaternary Research* 45: 188-201.

Hu, F., Ito, E., Brubaker, B., & Anderson, P.M. 1998. Ostracode geochemical records of Holocene climate change and implication for vegetation response in the northwestern Alaska range. *Quaternary Research* 49: 89-95.

Hu, F., Brubaker, L.B., Gavin, D.G., Higuera, P.E., Lynch, J.A., Rupp, T.S., & Tinner, W. 2006. How climate and vegetation influence the fire regime of the Alaskan boreal biome: The Holocene perspective. *Mitigation and Adaptation Strategies for Global Change* 11: 829-846.

IPCC Working Group II. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. IPCC Secretariat c/o World Meteorological Organization, 7 bis Avenue de la Paix, C.P. 2300, CH - 1211 Geneva 2, Switzerland.

Jacoby, G.C. & D'Arrigo, R.D. 1995. Tree ring width and density evidence of climatic and potential forest change in Alaska. *Global Biogeochemical Cycles* 9: 227-234.

Johnstone, J.F., Chapin III, F.S., Foote, J., Kemmett, S., Price, K., & Viereck, L. 2004. Decadal observations of tree regeneration following fire in boreal forests. *Canadian*

Journal of Forest Research 34: 267-273.

Kalff, J. 2002. *Limnology.* Prentice Hall, New Jersey, USA.

Kaplan, M.R., Wolfe, A.P., & Miller, G.H. 2002. Holocene environmental variability in Southern Greenland inferred from lake sediments. *Quaternary Research* 58: 149-159.

Kapp, R. 2000. *How to know Pollen and Spores.* American Association of Stratigraphic Palynologists Foundation publication.

Keenan, T.J. & Cwynar, L.C. 1982. Late quaternary history of black spruce and grasslands in southwest Yukon Territory. *Canadian Journal of Botany* 70: 1,336-1,345.

Kurek, J., Cwynar, L.C., Ager, T.A., Abbott, M.B., & Edwards, M.E. 2009. Late Quaternary paleoclimate of western Alaska inferred from fossil chironomids and its relation to vegetation histories. *Quaternary Science Reviews* 28(9-10): 799-811.

Lacourse, T. & Gajewski, K. 2000. Late quaternary vegetation history of Sulphur Lake, southwest Yukon Territory, Canada. *Arctic* 53: 27-35.

Levesque, A.J., Cwynar, L.C., & Walker, I.R. 1994. A multiproxy investigation of late-glacial climate and vegetation change at Pine Ridge Pond, southwest New Brunswick, Canada. *Quaternary Research* 42: 316–327.

Lowe, J. & Walker, M.J.C. 1997. *Reconstructing Quaternary Environments.* Prentice Hall, Toronto.

Lynch, J., Clark, J.S., Bigelow, N.H., Edwards, M.E., & Finney, B.P. 2003. Geographic and temporal variations in fire history in boreal ecosystems of Alaska. *Journal of Geophysical Research* 108(D1): 8,152, doi: 10.1029/2001JD000332.

Lynch, J., Hollis, J., & Hu, F. 2004. Climatic and landscape controls of the boreal forest fire regime: Holocene records from Alaska. *Journal of Ecology* 92: 477-489.

MacDonald, G.M., Beukens, R.P., & Kieser, W.E. 1991. Radiocarbon Dating of Limnic Sediments: A Comparative Analysis and Discussion. *Ecology* 72: 1,150-1,155.

MacDonald, G.M. 2003. *Biogeography: Introduction to Space, Time, and Life.* John Wiley and Sons, New York.

McAndrews, J.H., Berti, A.A., & Norris, G. 1973. *Key to the Quaternary pollen and spores of the Great Lakes Region.* Royal Ontario Museum, Miscellaneous publication.

McCoy, V.M. & Burn, C.R. 2005. Potential alteration by climate change of the forest-fire regime in the boreal forest of central Yukon Territory. *Arctic* 58: 276-285.

McKay, N.P., Kaufman, D.S., & Michelutti, N. 2008. Biogenic silica concentration as a high resolution, quantitative temperature proxy at Hallet Lake, south-central Alaska. *Geophysical Research Letters* 35: L05709.

McManus, J., Oppo, D.W., & Cullen, J. 1999. A 0.5 million-year record of millennial-scale climate variability in the North Atlantic. *Science* 283: 971-974.

Michelutti, N., Douglas, M., Wolfe, A., & Smol, J.P. 2008. Heightened sensitivity of a poorly buffered high arctic lake to late-Holocene climatic change. *Quaternary Research* 65(3): 421-430.

Minckley T.A., Whitlock, C., & Bartlein, P.J. 2007. Vegetation, fire, and climate history of the northwestern Great Basin during the last 14,000 years. *Quaternary Science Reviews* 26: 2,167–2,184.

Moore, P.D. & Webb, J.A. 1978. *An illustrated guide to pollen analysis*. Wiley, New York, USA.

Müller, B., Lötter, A.F., Sturm, M., & Ammann, A. 1998. Influence of catchment quality and altitude on the water and sediment composition of 68 small lakes in Central Europe. *Aquatic Sciences* 60: 316-337.

National Atlas Information Service. 1995. Canada, Permafrost. The National Atlas of Canada Map (5^{th} ed) MCR 4177, Scale 1:7,500,000.

Oppo, D.W., McManus, J., & Cullen, J. 1998. Abrupt climate evens 500000 to 340000 years ago: Evidence from subpolar North Atlantic sediments. *Science* 279: 1335-1338.

Overpeck, J., Webb III, T., & Prentice, I.C. 1985. Quantitative interpretation of fossil pollen spectra: dissimilarity coefficients and the method of modern analogues. *Quaternary Research* 23: 87-108.

Overpeck, J., Hughen, K., Hardy, D., Bradley, R., Case, R., Douglas, M., Finney, B., Gajewski, K., Jacoby, S., Jennings, A., Lamoureux, S., Lasca, A., MacDonald, G., Moore, J., Retelle, M., Smith, S., Wolfe, A., & Zielinski, G. 1997. Arctic Environmental Change of the Last Four Centuries. *Science* 278: 1,251-1,256.

Pisaric, M.F.J., MacDonald, G.M., Velichko, A.A., & Cwynar, L.C. 2001. The lateglacial and post-glacial vegetation history of the northwestern limits of Beringia, based on pollen, stomate, and tree stump evidence. *Quaternary Science Reviews* 20: 235-245.

Rampton, V. 1971. Late Pleistocene glaciation of the Snag-Klutlan area, Yukon Territory. *Arctic* 24: 277-300.

Raymo, M.E., Ganley, K., Carter, S., Oppo, D.W., & McManus, J. 1998. Millennial-scale climate instability during the early Pleistocene epoch. *Nature* 392: 699-702.

Reimer, P., Baillie, M., Bard, E., Bayliss, A., Beck, J., Bertrand, C., Blackwell, P., Buck, C., Burr, G., Cutler, K., Damons, P., Edwards, R., Fairbanks, R., Friedrich, M., Guilderson, T., Hogg, A., Hughen, K., Kromer, B., McCormac, G., Manning, S., Ramsey, C., Reimer, R., Remmele, S., Southon, J., Stuiver, M., Talamo, S., Taylor, F., van der Plicht, J., & Weyhenmeyer, C. 2004. INTCAL04 Terrestrial radiocarbon age calibration, 0-26 cal kyr BP. *Radiocarbon* 46: 1,029-1,058.

Richter, D.H., Preece, S.J., McGimsey, R.G., & Westgate, J.A. 1995. Mount Churchill, Alaska: source of the late Holocene White River Ash. *Canadian Journal of Earth Sciences* 32: 741-748.

Ritchie, J.C. 1982. The modern and late Quaternary vegetation of the Doll Creek area, north Yukon, Canada. *New Phytologist* 90: 563-603.

Robinson, S.D. 2001. Extending the late Holocene White River Ash distribution, northwestern Canada. *Arctic* 54: 157-161.

Sandgren, P. & Snowball, I. 2001. Application of Mineral Magnetic Techniques to Paleolimnology. In, J.P.Smol & W.M. Last (Eds.), *Tracking Environmental Change Using Lake Sediments. Volume 2: Physical and Geochemical Methods.* Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 217-237.

Sawada, M., Viau, A.E., Vettoretti, G., Peltier, W.R., & Gajewski, K. 2004. Comparison of North American pollen-based temperature and global lake status with CCCma AGCM2 output at 6ka. *Quaternary Science Reviews* 23: 225-244.

Sawada, M. 2006. An open source implementation of the modern analogue technique (MAT) within the R computing environment. *Computers and Geosciences* 32: 818-833.

Shaw, P. 2003. *Multivariate Statistics for the Environmental Sciences*. Arnold Publishers, London.

Sirois, L. & Payette, S. 1989. Postfire black spruce establishment in subarctic and boreal Quebec. *Canadian Journal of Forest Research* 19: 1,571–1,580.

Smol, J.P. 2002. *Pollution of lakes and rivers: a paleonvironmental perspective*. Oxford Press Inc., New York, USA.

Stuart, G.S.L., Helmer, J.W., & Hills, L.V. 1989. The Holocene paleoecology of Jenny Lake area, southwest Yukon, and its implications for prehistory. *Arctic* 42: 347-353.

Szeicz, J.M. & MacDonald, G.M. 2001. Montane climate and vegetation dynamics in easternmost Beringia during the late Quaternary. *Quaternary Science Reviews* 20: 247-257.

Tinner, W., Hu, F., Beer, R., Kaltenrider, P., Scheurer, B., & Krahenbuhl, U. 2006. Post-glacial vegetation and fire history: pollen, plant macrofossil, and charcoal records from two Alaskan lakes. *Vegetation History and Archaeobotany* 15: 279-293.

Tinner, W. & Hu, F.S. 2001. Responses of fire and vegetation to Little-Ice-Age climatic change in boreal Alaska. *The Ecological Society of America 86th Annual Meeting, Madison, WI, USA*, 221.

Tinner, W. & Hu, F.S. 2003. Size parameters, size-class distribution and area-number relationship of microscopic charcoal: Relevance for fire reconstruction. *Holocene* 13: 499–505.

Viau, A., Gajewski, K., Fines, P., Atkinson, D.E., & Sawada, M. 2002. Widespread evidence of 1500 yr climate climate variability in North America during the past 14000 yr. *Geology* 30(5): 455-458.

Viau, A.E., Gajewski, K., Sawada, M.C., & Fines, P. 2006. Millennial-scale temperature variations in North America during the Holocene. *Journal of Geophysical Research-Atmosphere* 111: D09102, DOI: 10.1029/2005JD006031.

Viau, A.E., Gajewski, K., Sawada, M.C., & Bunbury, J. 2008. Low-and high frequency climate variability in Eastern Beringia during the past 25,000 years. *Canadian Journal of Earth Sciences* 45: 1435-1453. DOI: 10.1139/E08-036.

Wang, X.-C. & Guerts, M.-A. 1991a. Late Quaternary pollen records and vegetation history of the southwest Yukon Territory: A review. *Geographie physique et quaternaire* 45: 175-193.

Wang, X.-C. & Guerts, M.-A. 1991b. Post-glacial vegetation history of the Ittlemit lake basin, southwest Yukon Territory. *Arctic* 44: 23-30.

Wang, X.-C. 1989. *Pot-glacial vegetation history of the Aishihik basin and its vicinity, southwest Yukon Territory: A palynologial perspective*. PhD Thesis. University of Ottawa. 544pp.

Whitlock, C. & Larsen, C. 2001. Charcoal as a fire proxy. In, J.P. Smol, H.J.B. Birks, & W.M. Last (Eds.), *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 75-97.

Whitlow, S.I., Mayewski, P.A., Holdsworth, G., Twickler, M.S., & Dibb, J.E. 1994. An ice core based record of biomass burning in the arctic and subarctic, 1750-1980. *Tellus* 46: 234-242.

Whitmore, J., Gajewski, K., Sawada, M., Williams, J.W., Shuman, B., Bartlein, P.J., Minckley, T., Viau, A.E., Webb III, T., Shafer, S., Anderson, P., & Brubaker, L. 2005. Modern pollen data from North America and Greenland for multi-scale paleoenvironmental applications. *Quaternary Science Reviews* 24: 1,828-1,848.

Whittmire, C.M. 2000. *Vegetative and fire history of the area surrounding Keyhole Pond, Yukon Territory*. M.Sc. Thesis. University of Regina.

Willard, D.A., Bernhardt, C.E., Brooks, G.R., Cronin, T.M., Edgar, T., & Larson, R. 2007. Deglacial climate variability in central Florida, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology* 251: 366-382.

Williams, J. & Shuman, B. 2008. Obtaining accurate and precise environmental reconstructions from the modern analog technique and North American surface pollen dataset. *Quaternary Science Reviews 27*(7-8): 669-687.

Wright, Jr., H.E. 1967. A square-rod piston sampler for lake sediments. *Journal of Sedimentary Petrology* 37: 957-976.

Yarie, J. 1983. Environmental and successional relationships of the forest communities of the Porcupine River drainage, interior Alaska. *Canadian Journal of Forest Research* 13: 721–728.

Yalcin, K. & Wake, C.P. 2001. Anthropogenic signals recorded in an ice core from Eclipse Icefield, Yukon Territory, Canada. *Geophysical Research Letters* 28(23): 4487-4490.

Yalcin, K., Wake, C.P., Kreutz, K.J., & Whitlow, S.I. 2006. A 1,000-yr record of forest fire activity from Eclipse Icefield, Yukon, Canada. *The Holocene* 16: 200-209.

Zabenskie, S., Peros, M., & Gajewski, K. 2006. The use of heavy-liquid in the separation of pollen from Arctic lake sediments. *Canadian Association of Palynologists Newsletter* 29: 5-7.

Zabenskie, S. & Gajewski, K. 2007. Post-glacial climatic change on Boothia Peninsula, Nunavut, Canada. *Quaternary Research* 68: 261-270.

Zoladeski, C.A., & Maycock, P.F. 1990. Dynamics of the boreal forest in northwestern Ontario. *American Midland Naturalist* 124: 289–300.

Table 1.1. Climate data from the study region. Climate Normals from Environment Canada (1971-2000).

	Otter Falls	Burwash	Braeburn
Latitude	61°02'N	61°22'N	61°28'N
Longitude	137°03'W	139°03'W	135°47'W
Elevation (m)	830	807	716
Mean temperature (°C)			
Daily	-1.4	-3.8	-3.1
January	-16.4	-22.0	-21.2
July	13.1	12.8	13.6
Total precipitation (mm/yr)	297.3	279.7	279.8
Rain (mm/yr)	189.9	192.1	185.6
Snow (cm/yr)	107.4	106.4	94.4

Table 4.1. Climate data from the study region. Climate Normals from Environment Canada (1971-2000).

	Otter Falls	Burwash	Braeburn
Latitude	61°02'N	61°22'N	61°28'N
Longitude	137°03'W	139°03'W	135°47'W
Elevation (m)	830	807	716
Mean temperature (°C)			
Daily	-1.4	-3.8	-3.1
January	-16.4	-22.0	-21.2
July	13.1	12.8	13.6
Total precipitation (mm/yr)	297.3	279.7	279.8
Rain (mm/yr)	189.9	192.1	185.6
Snow (cm/yr)	107.4	106.4	94.4

Table 4.2. ^{210}Pb dates for core WA01. Cal yrs BP based on reference year AD1950.

Top Depth (cm)	Bottom Depth (cm)	Average Depth (cm)	210Pb Activity	SD (+/-)	Years Per Slice	Cal yrs BP
0.0	0.5	0.25	2.05E-01	1.25E-02	0.7	-58.1
0.5	1.0	0.75	1.30E-01	2.24E-02	0.1	-57.7
1.0	1.5	1.25	2.06E-01	1.28E-02	0.7	-57.3
1.5	2.0	1.75	2.36E-01	1.43E-02	0.9	-56.5
2.0	2.5	2.25	2.52E-01	1.97E-02	0.3	-55.9
2.5	3.0	2.75	2.59E-01	1.51E-02	0.9	-55.3
3.0	3.5	3.25	2.37E-01	1.32E-02	1.1	-54.3
3.5	4.0	3.75	1.74E-01	9.94E-03	1.5	-53.0
4.0	4.5	4.25	1.53E-01	8.57E-03	1.0	-51.7
4.5	5.0	4.75	1.33E-01	6.77E-03	2.3	-50.0
5.0	5.5	5.25	1.19E-01	6.51E-03	2.2	-47.8
5.5	6.0	5.75	1.05E-01	6.22E-03	1.1	-46.1
6.0	6.5	6.25	1.01E-01	6.10E-03	1.8	-44.7
6.5	7.0	6.75	1.11E-01	6.12E-03	3.2	-42.2
7.0	7.5	7.25	1.06E-01	5.88E-03	2.1	-39.5
7.5	8.0	7.75	8.17E-02	5.03E-03	1.8	-37.5
8.0	8.5	8.25	8.93E-02	4.89E-03	2.8	-35.2
8.5	9.0	8.75	9.23E-02	5.34E-03	1.7	-33.0
9.0	9.5	9.25	8.85E-02	4.69E-03	2.7	-30.8
9.5	10.0	9.75	8.47E-02	4.79E-03	2.6	-28.2
10.0	10.5	10.25	8.06E-02	5.37E-03	3.1	-25.3
10.5	11.0	10.75	8.76E-02	5.22E-03	2.7	-22.5
11.0	11.5	11.25	7.70E-02	4.11E-03	3.4	-19.4
11.5	12.0	11.75	7.62E-02	4.84E-03	2.0	-16.7
12.0	12.5	12.25	7.10E-02	4.47E-03	2.7	-14.4
12.5	13.0	12.75	6.05E-02	4.05E-03	2.7	-11.7
13.0	13.5	13.25	6.60E-02	4.45E-03	3.1	-8.8
13.5	14.0	13.75	5.31E-02	3.27E-03	2.8	-5.8
14.0	14.5	14.25	4.44E-02	2.75E-03	2.8	-3.0
14.5	15.0	14.75	4.24E-02	2.42E-03	3.3	0.0

Table 4.3. Radiocarbon dates for core WA01.

Top Depth (cm)	Bottom Depth (cm)	Lab No.	Conventional 14C Age BP	Error (+/-)	2 Sigma Calibration	Average 2 sigma value (Cal yrs BP) or known date (WRA)	Notes
13	17	BETA-249092	160	40	Cal BP (290 to 0)	145	Twig
52	59	N/A	N/A	N/A	N/A	1147	White River Ash from Clague *et al.*, 1995
92	93	BETA-249091	3350	40	Cal BP (3690 to 3470)	3580	Wood fragments
128	129	BETA-249090	4260	40	Cal BP (4870 to 4820), (4740 to 4730)	4800	Wood fragments
188	190	BETA-249089	6470	40	Cal BP (7440 to 7310)	7375	Twig
208	209	BETA-249088	7300	50	Cal BP (8190 to 8010)	8100	Wood fragments
253	253	BETA-249087	9410	50	Cal BP (10740 to 10520)	10630	Twig

Table 4.4. Eigenvalues and explained variance of Principal Components Analysis (PCA) on fossil pollen data from Lake WA01.

Axis	Eigenvalues	Percent explained variance (cumulative)
1	3.888	21.6%
2	2.466	35.3%
3	1.584	44.1%
4	1.386	51.8%
5	1.224	58.6%

Table 4.5. Species loadings of Principal Components Analysis (PCA) on fossil pollen data from Lake WA01.

Species Name	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Picea glacua	-1.83	-0.88	0.65	0.62	-0.80
Picea mariana	0.29	-0.73	-0.66	-0.19	1.42
Pinus diploxylon	1.47	-1.31	0.67	-0.14	-0.01
Populus	1.32	-0.38	-0.31	1.90	0.62
Juniperus	0.40	0.81	-0.57	2.36	-0.62
Alnus crispa	0.53	0.90	1.68	-1.28	-0.04
Betula	0.90	1.66	-1.08	-1.06	0.68
Shepherdia	-0.32	-0.24	-0.68	0.41	1.95
Salix	0.82	1.61	-1.04	0.50	-0.42
Cyperaceae	1.28	0.15	1.63	0.15	0.62
Epilobium	-0.46	-0.31	-0.42	-0.52	2.50
Poaceae	1.00	1.08	0.32	-0.88	0.35
Polypodiaceae	0.13	1.23	1.02	1.36	0.15
Sphagnum	0.47	0.72	-0.35	-0.94	-1.25
AP	1.24	-1.57	0.61	-0.52	-0.49
NAP	1.34	-0.81	-1.23	0.36	-0.15
Spores	1.49	-1.09	-0.09	0.06	-0.53
Aquatics	0.10	0.57	2.18	0.99	1.11

Table 4.6. Sample scores of Principal Components Analysis (PCA) on fossil pollen data from Lake WA01.

Mean cm	Age BP	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
1.5	-59.00	0.44	0.57	1.19	0.33	0.61
2.5	-58.11	0.46	-0.17	0.65	0.27	0.35
3.5	-56.41	0.77	0.45	0.80	-0.34	0.14
4.5	-53.93	0.24	-0.15	0.27	-0.04	-0.05
5.5	-50.64	0.11	0.36	0.83	0.56	0.23
6.5	-46.56	-0.18	0.24	0.60	0.23	0.07
7.5	-41.68	-0.38	0.26	0.55	0.43	0.15
8.5	-36.00	-0.41	-0.08	0.23	-0.15	-0.10
9.5	-29.53	-0.32	0.09	0.61	0.20	0.24
10.5	-22.27	-0.09	-0.19	0.06	-0.06	-0.13
11.5	-14.21	-0.22	0.15	0.03	-0.03	-0.18
12.5	-5.35	0.04	0.41	0.59	0.16	-0.03
13.5	4.30	-0.06	-0.19	0.13	0.06	-0.28
14.5	14.76	0.01	0.11	-0.08	0.49	-0.06
15.5	26.42	-0.12	0.35	-0.05	0.06	0.01
17.5	53.74	-0.22	0.19	0.38	-0.05	0.25
18.5	69.35	-0.06	0.08	-0.05	-0.10	0.22
19.5	86.23	0.14	0.38	0.30	-0.28	-0.05
20.5	104.36	-0.21	-0.30	-0.38	-0.05	0.97
21.5	123.70	0.54	0.61	-0.11	-0.33	-0.45
22.5	144.25	0.47	-0.54	-0.14	0.07	-0.09
23.5	165.98	-0.03	-0.38	-0.47	0.13	0.55
24.5	188.86	-0.73	-0.08	-0.06	-0.02	-0.18
25.5	212.87	-0.39	-0.24	-0.05	-0.02	-0.17
26.5	237.99	-0.57	-0.14	0.08	0.09	-0.14
27.5	264.19	0.27	-0.27	-0.13	0.37	0.30
28.5	291.46	0.67	0.66	-0.11	1.01	-0.21
29.5	319.76	-0.43	-0.11	0.04	-0.17	-0.15
30.5	349.08	-0.43	-0.20	0.00	-0.14	-0.18
31.5	379.38	-0.21	-0.07	0.14	0.33	-0.03
33.5	442.89	-0.28	0.14	0.25	-0.27	-0.05
34.5	476.03	-0.20	-0.07	0.14	-0.19	-0.09
35.5	510.08	0.64	0.39	-0.06	-0.52	-0.54
36.5	545.00	-0.46	-0.10	0.06	-0.02	-0.14
37.5	580.77	0.72	-0.46	-0.09	0.10	-0.12
38.5	617.38	1.01	-0.20	-0.26	0.42	-0.09
39.5	654.79	0.33	-0.56	0.24	-0.09	-0.01
40.5	692.98	-0.30	0.05	0.12	-0.04	0.15
41.5	731.94	0.46	-0.11	0.15	-0.03	-0.13
42.5	771.63	0.54	-0.61	0.34	0.08	0.10
43.5	812.03	0.97	-0.73	0.33	-0.13	-0.05
44.5	853.13	0.42	0.00	0.07	-0.15	-0.20

Table 4.6 cont'd. Sample scores of Principal Components Analysis (PCA) on fossil pollen data from Lake WA01.

Mean cm	Age BP	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
49.5	1068.17	-0.48	-0.05	0.19	0.05	-0.16
56.5	1391.76	-0.01	0.22	0.29	-0.43	0.00
60.5	1585.75	0.37	-0.19	0.10	0.37	-0.16
65.5	1834.76	-0.27	0.29	-0.13	-0.19	0.04
68.5	1986.53	-0.04	0.02	-0.04	0.24	-0.07
70.5	2088.31	0.48	-0.52	-0.11	0.14	0.49
72.5	2190.36	-0.54	-0.14	0.05	0.13	-0.13
74.5	2292.48	0.07	-0.09	0.28	-0.27	0.03
76.5	2394.49	0.13	-0.10	-0.27	0.66	-0.21
77.5	2445.40	1.01	-0.90	0.11	0.12	-0.06
78.5	2496.22	0.77	-0.07	0.33	-0.44	0.30
79.5	2546.91	-0.10	0.36	0.41	-0.29	-0.04
81.5	2647.85	-0.68	-0.05	-0.02	-0.17	-0.04
84.5	2797.78	-0.67	-0.30	-0.42	-0.15	1.43
88.5	2993.97	-0.57	-0.14	-0.15	0.05	0.24
92.5	3184.54	0.06	-0.48	-0.04	-0.07	-0.14
97.5	3416.60	-0.47	0.06	0.07	-0.16	-0.02
100.5	3554.71	0.01	0.05	0.16	0.19	-0.12
104.5	3737.67	-0.53	0.02	0.11	-0.12	-0.10
108.5	3919.36	0.11	-0.14	-0.03	-0.06	-0.19
113.5	4144.85	-0.66	-0.07	-0.09	-0.12	-0.02
116.5	4279.34	-0.52	-0.16	-0.10	-0.08	0.02
120.5	4457.84	-0.42	-0.09	0.01	-0.14	-0.21
122.5	4546.75	0.33	-0.66	0.04	-0.17	0.04
124.5	4635.46	-0.11	-0.20	0.11	-0.22	0.15
125.5	4679.75	-0.69	-0.21	-0.14	-0.04	-0.02
126.5	4723.98	0.36	-0.27	-0.13	-0.11	-0.06
127.5	4768.18	-0.21	0.17	-0.05	-0.02	-0.22
129.5	4856.44	-0.59	-0.01	0.06	-0.05	-0.13
130.5	4900.50	0.04	0.12	0.01	-0.12	-0.03
132.5	4988.53	-0.08	0.01	0.17	-0.40	-0.30
136.5	5164.16	-0.53	0.04	-0.11	-0.02	-0.13
140.5	5339.34	0.21	0.34	-0.12	-0.10	-0.32
145.5	5557.81	-0.48	0.09	0.05	-0.14	-0.13
148.5	5688.71	-0.19	-0.13	-0.33	-0.14	0.11
152.5	5863.11	-0.56	0.03	-0.04	0.03	-0.23
156.5	6037.45	-0.21	-0.08	-0.20	-0.11	-0.20
161.5	6255.44	-0.55	-0.01	0.00	-0.22	0.46
164.5	6386.35	0.09	0.08	-0.10	0.33	-0.22
168.5	6561.12	-0.32	-0.01	-0.08	0.01	0.00
170.5	6648.63	0.34	-0.46	-0.06	-0.03	-0.13
172.5	6736.23	-0.12	-0.27	-0.24	-0.07	-0.19

Table 4.6 cont'd. Sample scores of Principal Components Analysis (PCA) on fossil pollen data from Lake WA01.

Mean cm	Age BP	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
174.5	6823.95	-0.03	-0.26	0.10	-0.20	-0.08
177.5	6955.77	-0.46	0.05	-0.20	0.05	0.09
178.5	6999.77	0.16	-0.21	0.08	-0.30	-0.06
179.5	7043.82	0.06	0.22	-0.16	-0.31	0.04
180.5	7087.90	-0.17	-0.13	0.03	-0.24	-0.01
181.5	7132.02	0.99	-0.51	-0.38	0.54	-0.29
184.5	7264.66	-0.62	0.10	-0.22	0.26	-0.15
188.5	7442.16	0.05	0.21	-0.01	-0.09	-0.38
193.5	7665.24	-0.68	0.00	-0.21	0.04	-0.21
200.5	7980.17	-0.34	-0.03	-0.49	0.42	0.15
204.5	8161.68	0.35	-0.56	-0.16	-0.18	-0.12
209.5	8390.33	-0.30	0.21	-0.27	0.62	-0.16
212.5	8528.55	-0.62	-0.08	-0.22	-0.05	-0.20
216.5	8714.11	0.16	0.50	-0.05	1.03	-0.07
220.5	8901.24	-0.08	-0.55	-0.20	-0.01	0.40
225.5	9137.48	-0.58	0.20	-0.29	0.39	-0.02
228.5	9280.55	-0.13	-0.20	-0.01	-0.24	0.10
232.5	9472.95	-0.53	0.23	-0.35	0.28	-0.08
236.5	9667.30	0.28	-0.11	-0.29	-0.13	-0.15
241.5	9913.15	0.37	1.07	-0.18	0.14	0.25
242.5	9962.72	0.57	0.58	0.04	-0.47	0.25
243.5	10012.43	0.67	1.29	-0.48	-0.47	0.15
244.5	10062.28	0.28	0.62	-0.13	-0.33	-0.12
245.5	10112.28	0.51	0.28	-0.57	-0.30	0.12
246.5	10162.41	1.29	-0.22	-0.49	-0.19	-0.01
247.5	10212.69	0.68	1.09	-0.55	-0.14	0.06
248.5	10263.12	0.44	1.08	-0.71	0.06	0.52
249.5	10313.69	0.94	-0.49	-0.34	-0.06	0.22

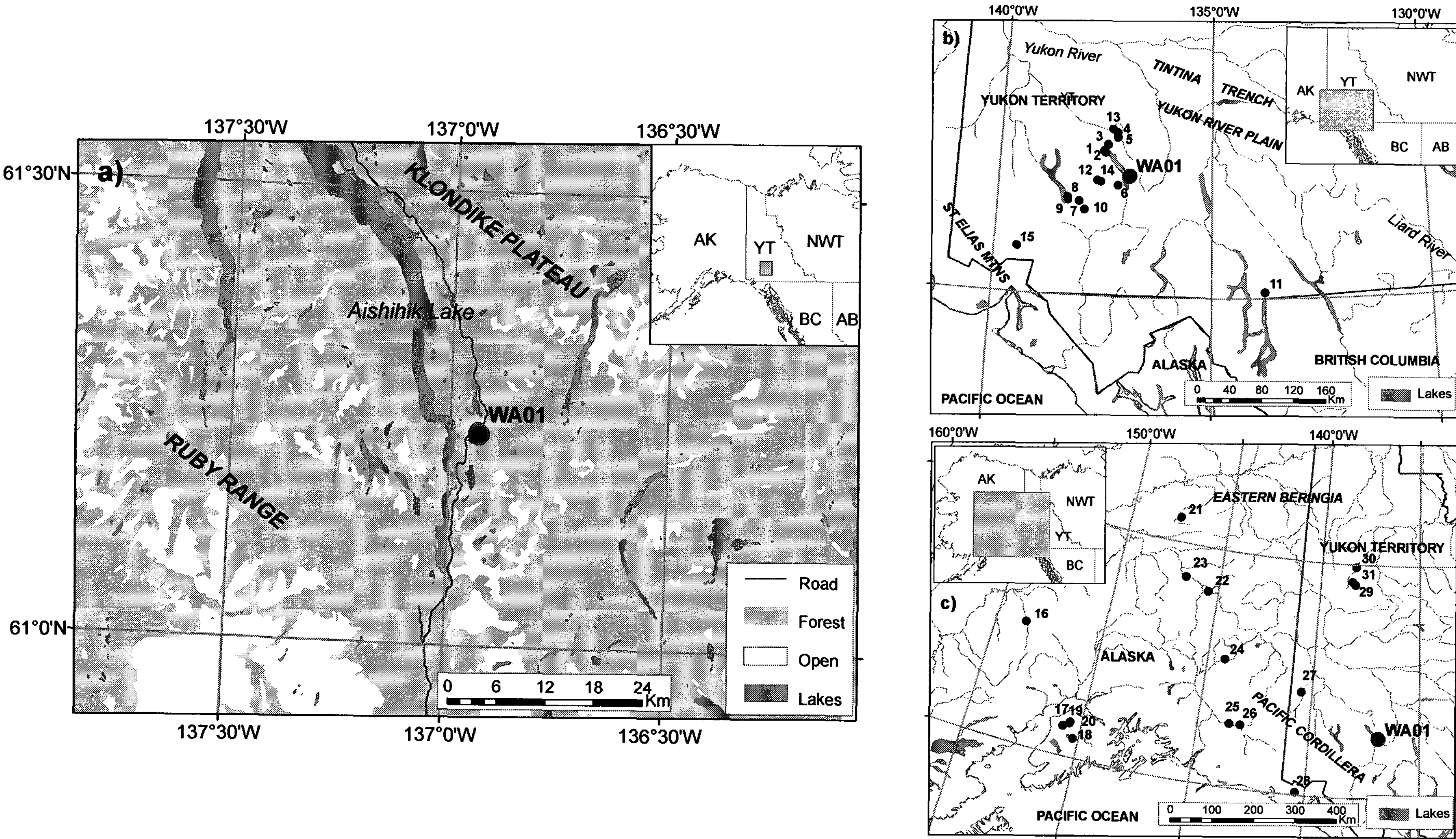


Figure 1.1. Location of the study site and of other locations referred to in the text. Location of the study site, Lake **WA01**; numbered points refer to the location of other studies in the area. a) **1** - XW-5, **2** - XW-6, **3** - XW-4, **4** - XW-2, **5** - XW-3, **6** - XW-7 (Wang, 1989). b) **7** - Keyhole Pond (Whittmire, 2000), **8** - Jenny Lake (Stuart *et al.*, 1989), **9** - Upper Fly Lake (Bunbury & Gajewski, 2009a), **10** - Sulphur Lake (Lacourse & Gajewski, 2000), **11** - Kettlehole Pond (Cwynar, 1988), **12** - XW-8, **13** - XW-1, **14** - XW-13 (Wang, 1989), **15** - Eclipse Icefield (Yalcin *et al.*, 2006). c) **16** - Farewell Lake (Hu *et al.*, 1996, 1998), **17** - Paradox Lake (Anderson *et al.*, 2006), **18** - Portage Lake, **19** - Arrow Lake (Anderson *et al.*, 2006; Lynch *et al.*, 2003), **20** - Rock Lake, **21** - Deuce Lake (Lynch *et al.*, 2003), **22** - Dune Lake (Lynch *et al.*, 2003; Bigelow, 1997), **23** - Lost Lake, **24** - Grizzly Lake (Tinner *et al.*, 2006), **25** - Moose Lake, **26** - Choksana Lake (Lynch *et al.*, 2004), **27** - Antifreeze Pond (Rampton, 1971), **28** - Mount Logan (Whitlow *et al.*, 2004; Holdsworth *et al.*, 1996; Moore *et al.*, 2002), **29** - Honeymoon Pond, **30** - Grayday Pond, **31** - Monkshood Pond (Cwynar & Spear, 1991).

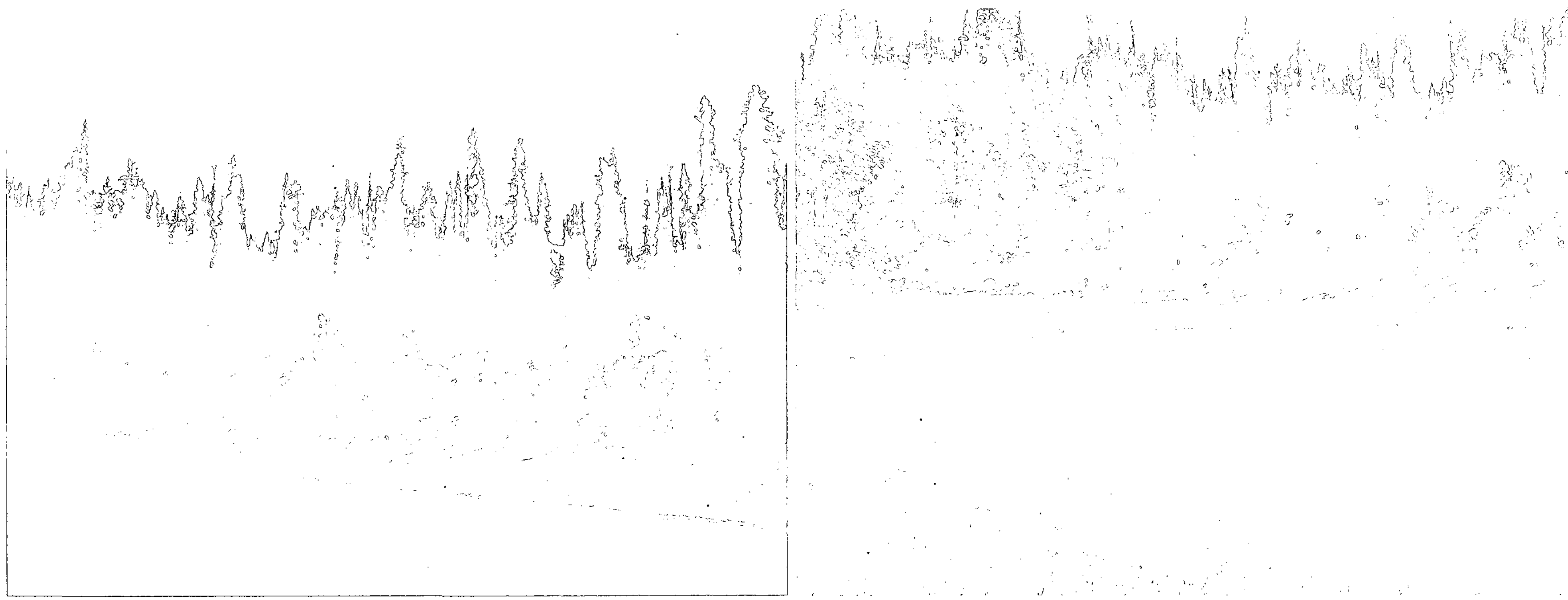


Figure 1.2. Lake WA01 showing evidence of previous shorelines.

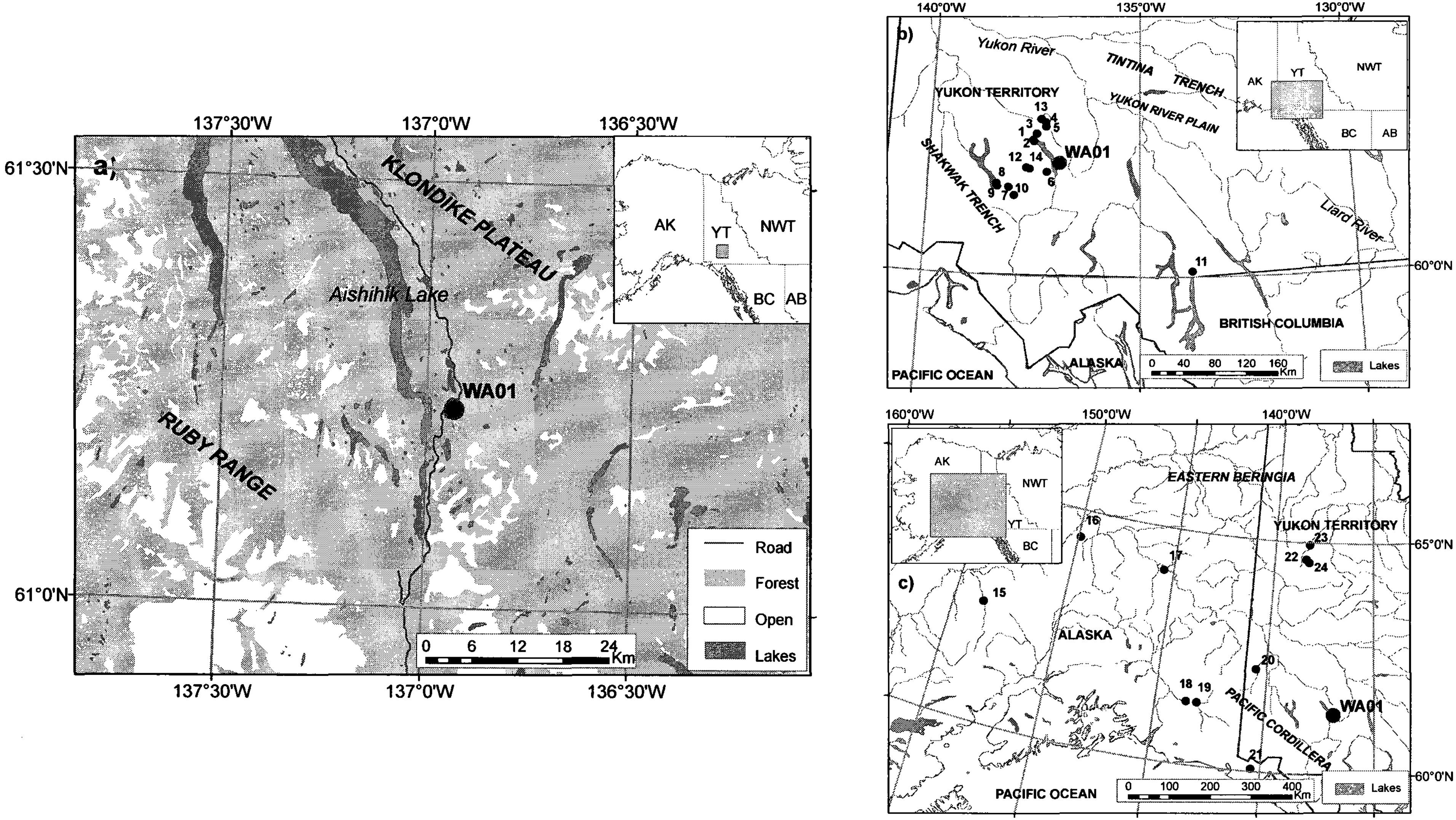


Figure 4.1. Location of the study site and of other locations referred to in the text. Location of the study site, Lake **WA01**; numbered points refer to the location of other studies in the area. a) **1** - XW-5, **2** - XW-6, **3** - XW-4, **4** - XW-2, **5** - XW-3, **6** - XW-7 (Wang, 1989). b) **7** - Keyhole Pond (Whittmire, 2000), **8** - Jenny Lake (Stuart *et al.*, 1989), **9** - Upper Fly Lake (Bunbury & Gajewski, 2009a), **10** - Sulphur Lake (Lacourse & Gajewski, 2000), **11** - Kettlehole Pond (Cwynar, 1988), **12** - XW-8, **13** - XW-1, **14** - XW-13 (Wang, 1989). c) **15** - Farewell Lake (Hu *et al.*, 1996, 1998), **16** - Birch Lake (Abbott *et al.*, 2000), **17** - Dune Lake (Lynch *et al.*, 2003; Bigelow, 1997), **18** - Moose Lake, **19** - Choksana Lake (Lynch *et al.*, 2004), **20** - Antifreeze Pond (Rampton, 1971), **21** - Mount Logan (Whitlow *et al.*, 2004; Holdsworth *et al.*, 1996; Moore *et al.*, 2002), **22** - Honeymoon Pond, **23** - Grayday Pond, **24** - Monkshood Pond (Cwynar & Spear, 1991).

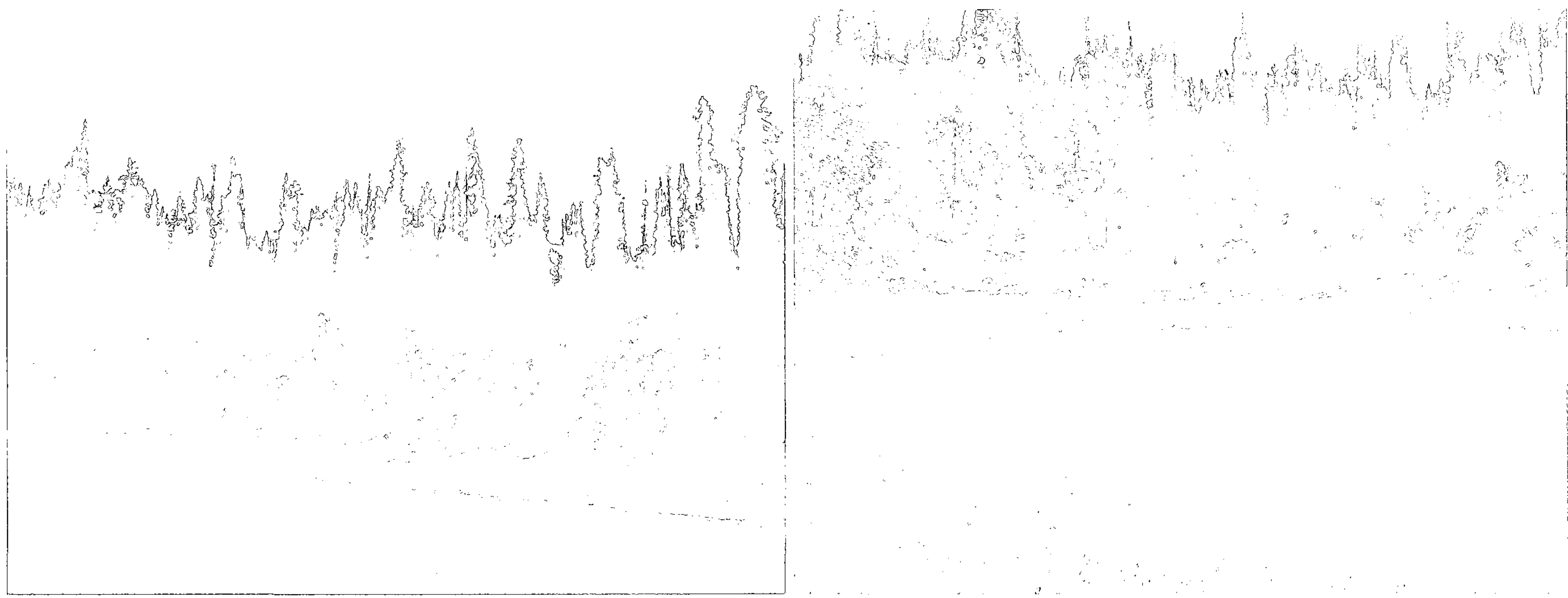


Figure 4.2. Lake WA01 showing evidence of previous shorelines.

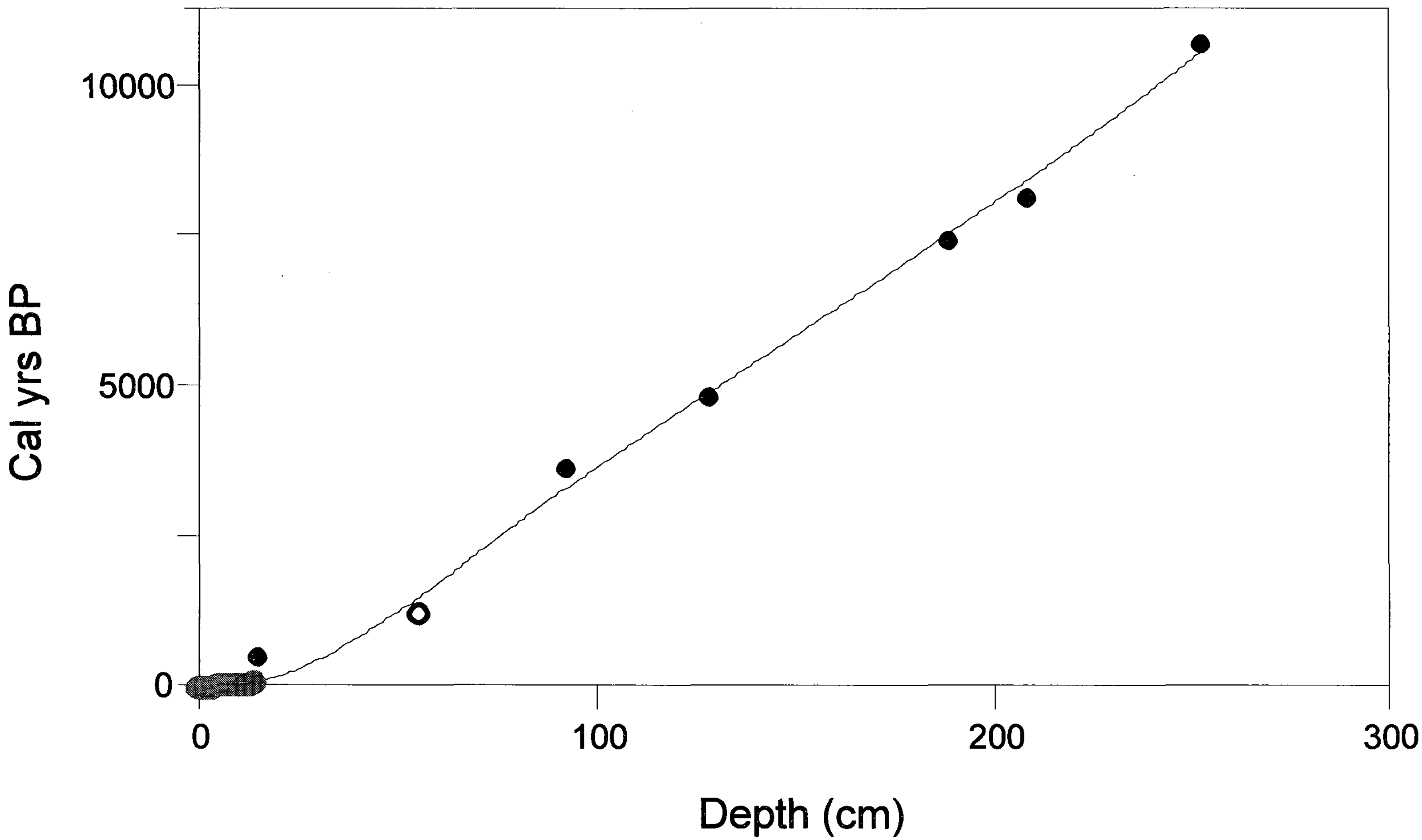


Figure 4.3. Lake WA01 chronology. The open circle represents the Clague *et al.* (1995) date of the White River Ash; the solid grey circles represent 210Pb dates; the solid black circles represent radiocarbon dates. Trend line is a loess smoother with a span of 0.9.

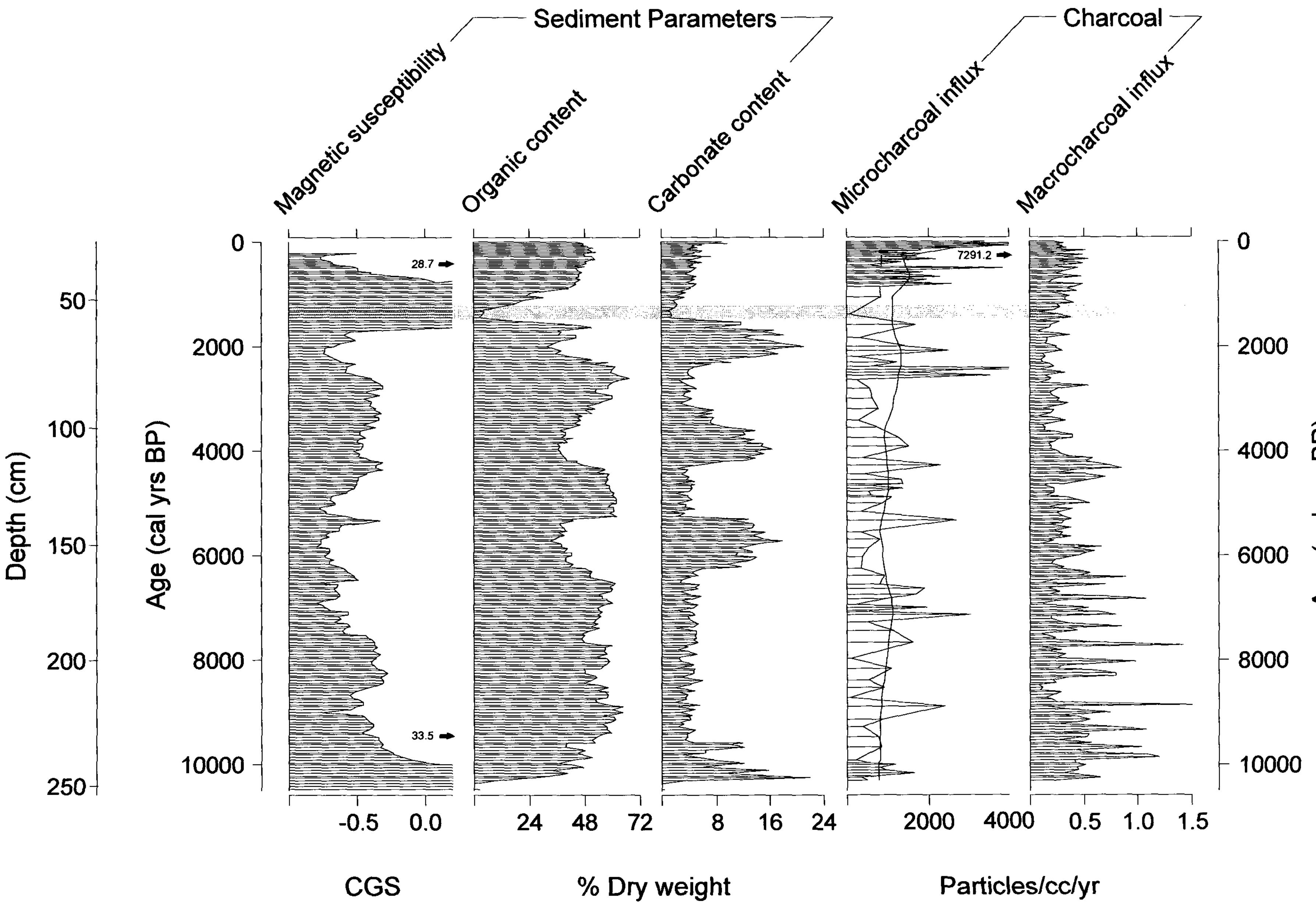


Figure 4.4. Lake WA01 magnetic susceptibility, loss-on-ignition, microcharcoal influx, and macrocharcoal influx. The area of grey shading represents the depth of the White River Ash. Trend line through the microcharcoal curve is a loess smoother with a span of 0.2. Note scale changes.

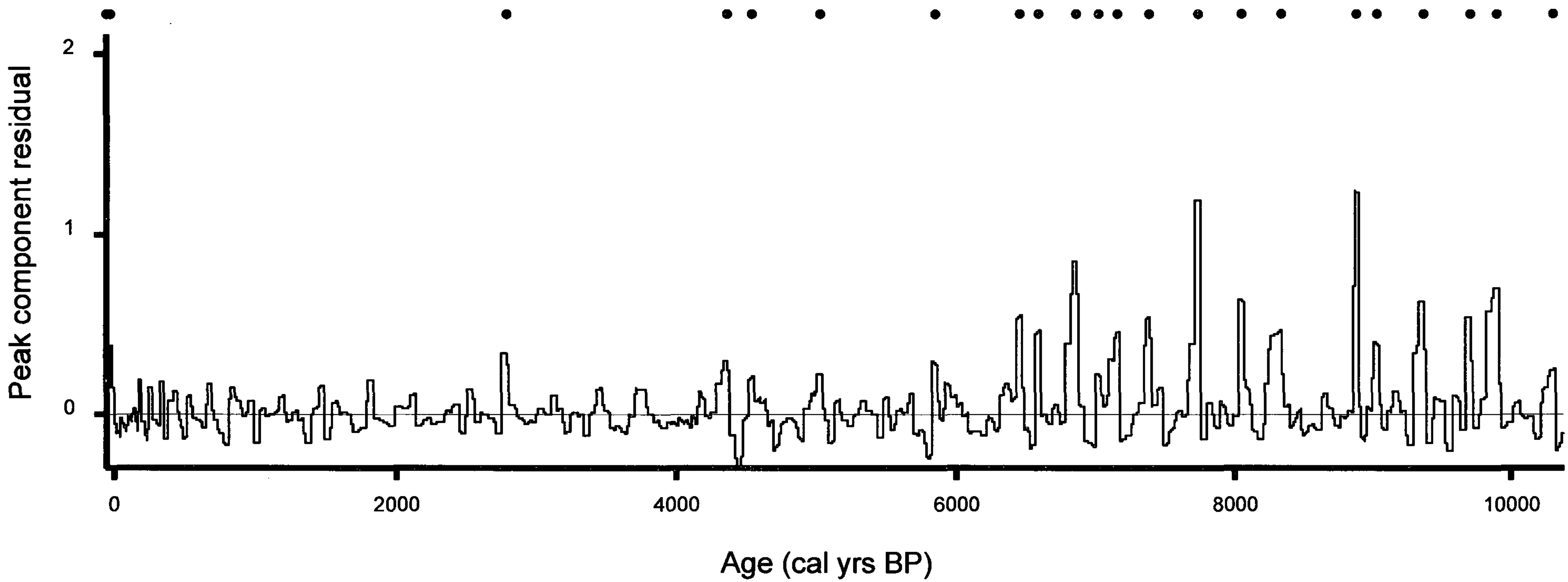


Figure 4.5. WA01 macrocharcoal influx (line) and Charster (http://geography.uoregon.edu/gavin/)-identified fire peaks (dots). The peak component is the charcoal series with the loess calculated background removed. Residuals are calculated as a simple difference (series-background).

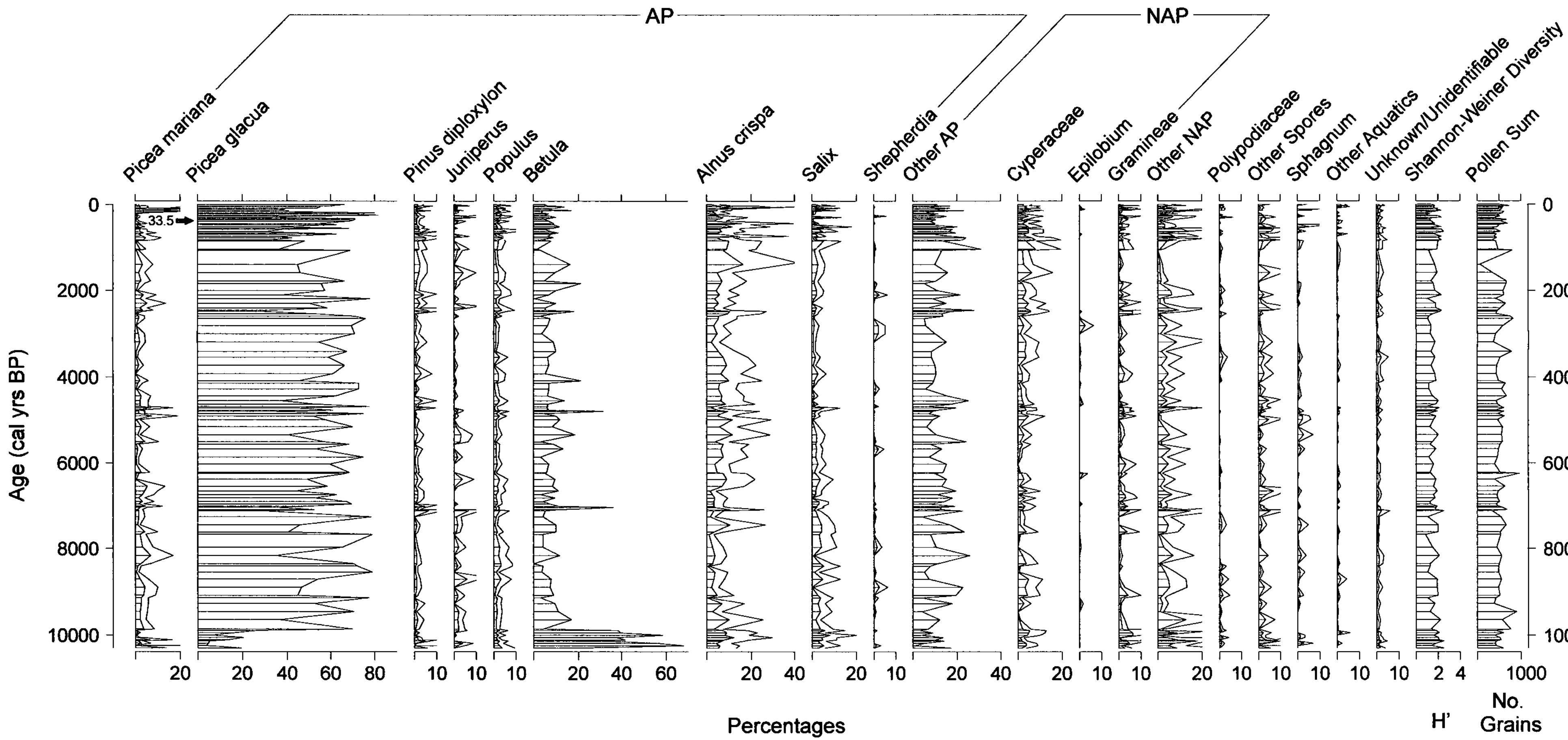


Figure 4.6. Summary pollen percentage diagram from Lake W A01. A 2.5-times exaggeration line has been added to a number of the curves so that patterns are more visible. Note scale changes in the last 2 diagrams.

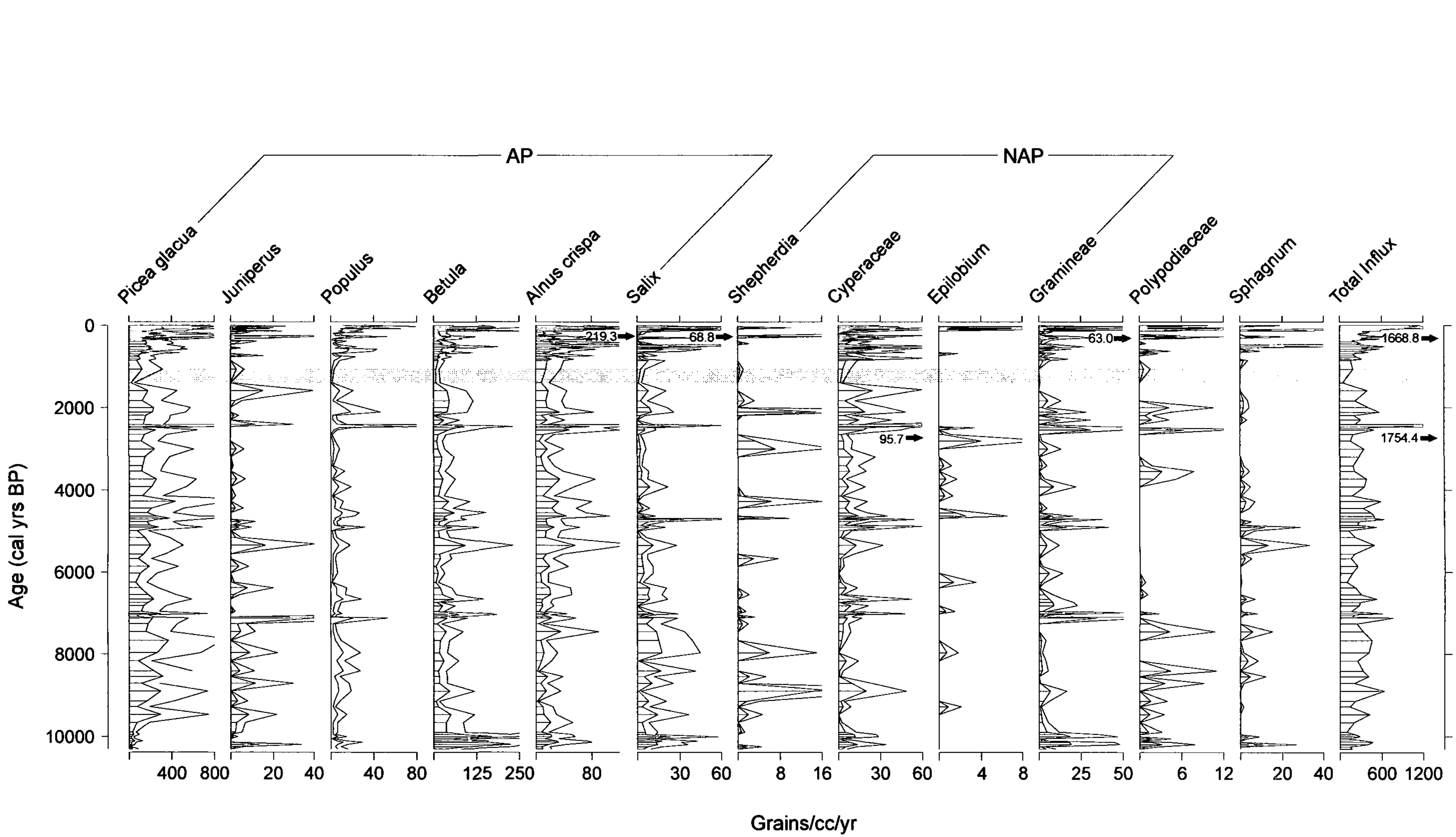


Figure 4.7. Pollen influx for selected taxa from Lake W A01. A 2.5-times exaggeration line has been added to a number of the curves so that patterns are more visible. The area of grey shading represents the depth of the White River Ash. Note scale changes.

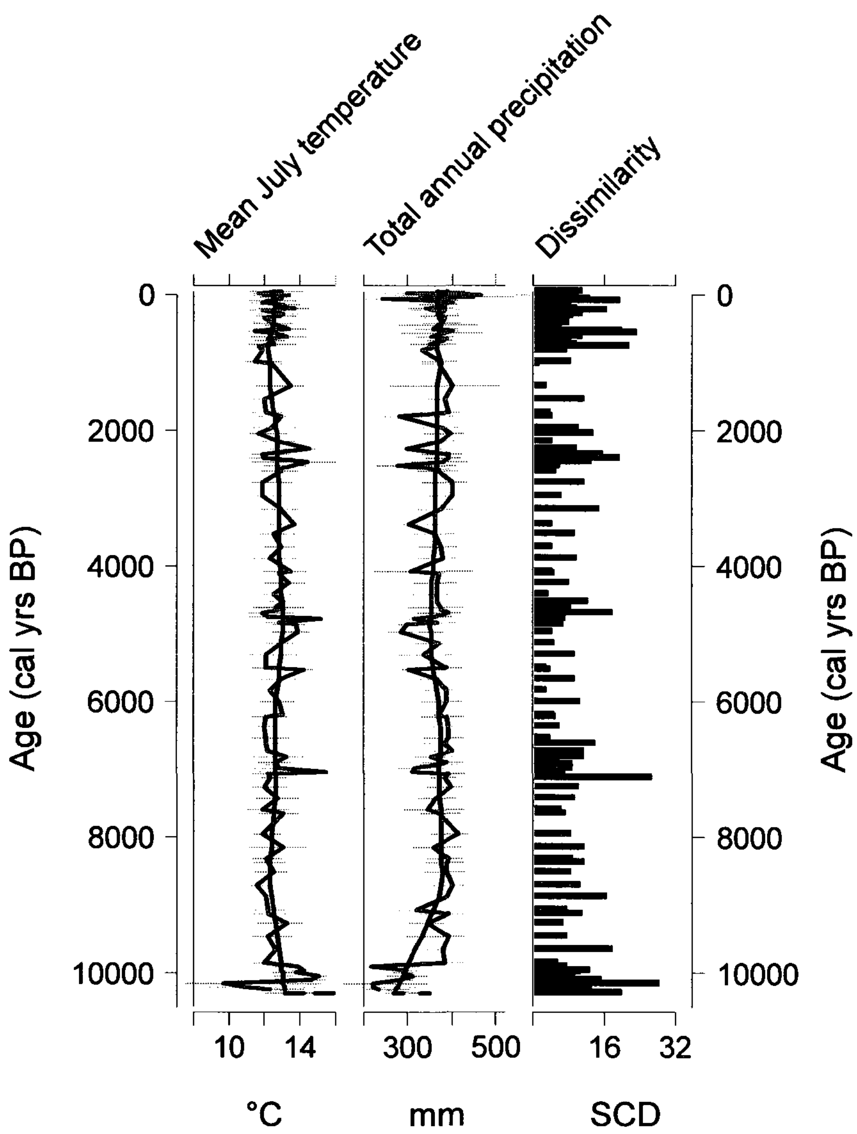
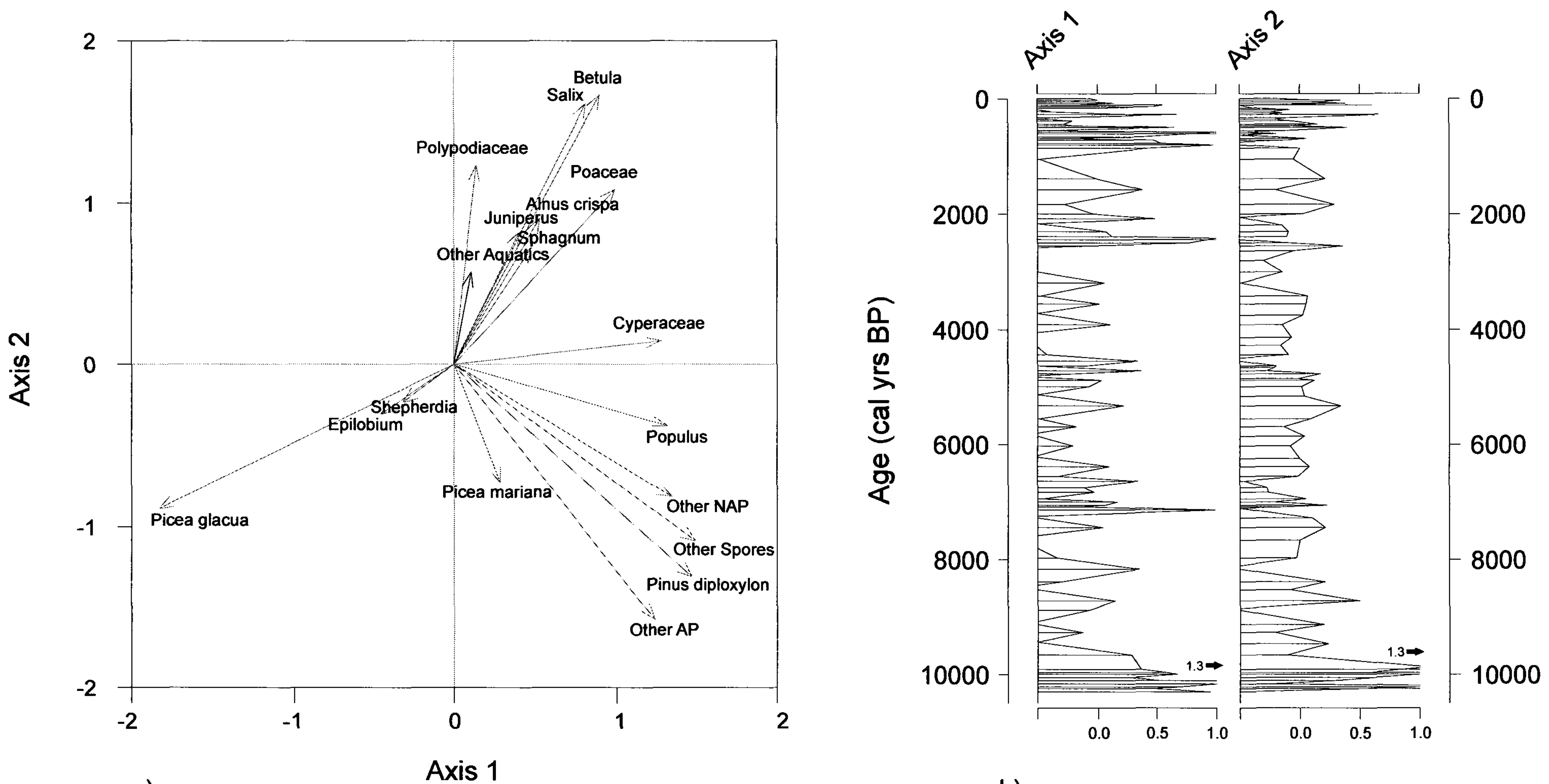


Figure 4.8. Pollen-based temperature and precipitation reconstructions for Lake WA01. The 3 best analogues identified by the MAT were retained for calculating reconstructed values. Trend lines through the temperature and precipitation values are loess smoothers with a span of 0.2. Note that the origin is not equal to zero in the first 2 diagrams.



a) b)

Figure 4.9. Principal components analysis of key fossil pollen taxa from Lake W A01. a) species loadings. b) sample scores.

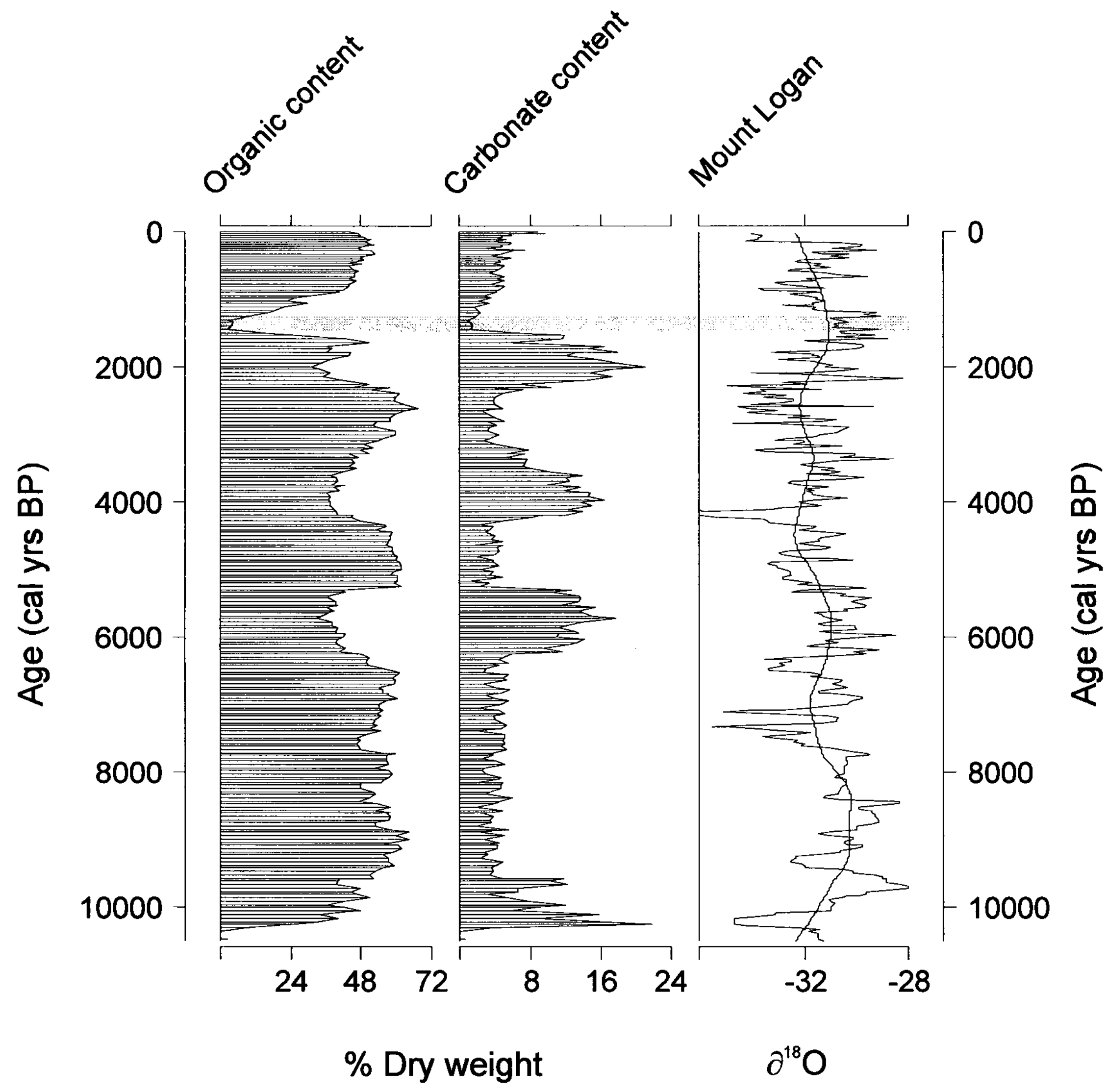


Figure 4.10. Lake WA01 sediment loss-on-ignition and Mount Logan $\partial^{18}O$ isotope record (Moore *et al.*, 2002). Trend line through the Logan curve is a loess smoother with a span of 0.2. The area of grey shading represents the depth of the White River Ash. Note scale changes.

Appendix A. Pollen data for Lake WA01

Upper Depth (cm)	Lower Depth (cm)	Average Depth (cm)	Cal yrs BP	*Picea glacua*	*Picea mariana*	*Picea* undiff
0	1	0.5		142.0	9.0	95.0
1	2	1.5	-59.0	228.0	0.0	15.0
2	3	2.5	-58.1	170.0	23.0	45.0
3	4	3.5	-56.4	106.0	10.0	49.5
4	5	4.5	-53.9	350.0	13.0	74.0
5	6	5.5	-50.6	273.0	3.0	27.5
6	7	6.5	-46.6	439.0	6.0	64.5
7	8	7.5	-41.7	468.0	4.0	39.5
8	9	8.5	-36.0	608.0	34.0	71.0
9	10	9.5	-29.5	284.0	5.0	31.5
10	11	10.5	-22.3	251.0	16.0	28.5
11	12	11.5	-14.2	411.0	1.0	36.5
12	13	12.5	-5.3	279.0	12.0	50.5
13	14	13.5	4.3	388.0	4.0	45.0
14	15	14.5	14.8	436.0	4.0	48.5
15	16	15.5	26.4	358.0	12.0	25.0
16	17	16.5	39.4	316.0	12.0	73.0
17	18	17.5	53.7	362.0	15.0	26.5
18	19	18.5	69.4	308.0	12.0	61.0
19	20	19.5	86.2	240.0	38.0	84.5
20	21	20.5	104.4	250.0	197.0	50.5
21	22	21.5	123.7	197.0	11.0	65.0
22	23	22.5	144.3	191.0	9.0	60.0
23	24	23.5	166.0	273.0	230.0	48.0
24	25	24.5	188.9	532.0	12.0	38.0
25	26	25.5	212.9	421.0	2.0	58.5
26	27	26.5	238.0	445.0	1.0	26.0
27	28	27.5	264.2	273.0	5.0	52.0
28	29	28.5	291.5	171.0	4.0	42.5
29	30	29.5	319.8	363.0	1.0	15.5
30	31	30.5	349.1	526.0	3.0	52.5
31	32	31.5	379.4	412.0	4.0	34.0
33	34	33.5	442.9	412.0	16.0	60.5
34	35	34.5	476.0	377.0	3.0	31.0
35	36	35.5	510.1	174.0	9.0	68.5
36	37	36.5	545.0	307.0	1.0	32.5
37	38	37.5	580.8	202.0	11.0	60.0
38	39	38.5	617.4	183.0	12.0	25.0
39	40	39.5	654.8	213.0	17.0	47.5
40	41	40.5	693.0	340.0	10.0	42.0
41	42	41.5	731.9	179.0	16.0	37.0
42	43	42.5	771.6	231.0	25.0	80.5
43	44	43.5	812.0	150.0	16.0	56.0

Upper Depth (cm)	Lower Depth (cm)	Average Depth (cm)	Cal yrs BP	*Picea glacua*	*Picea mariana*	*Picea* undiff
44	45	44.5	853.1	251.0	1.0	34.0
48	49	48.5	1024.0	207.0	11.0	156.0
49	50	49.5	1068.2	578.0	6.0	99.5
56	57	56.5	1391.8	114.0	8.0	11.0
60	61	60.5	1585.8	220.0	8.0	51.0
64	65	64.5	1784.5	480.0	20.0	66.5
65	66	65.5	1834.8	401.0	12.0	20.5
68	69	68.5	1986.5	383.0	3.0	66.5
70	71	70.5	2088.3	247.0	24.0	87.0
72	73	72.5	2190.4	421.0	10.0	39.0
74	75	74.5	2292.5	354.0	38.0	80.5
76	77	76.5	2394.5	354.0	13.0	22.5
77	78	77.5	2445.4	177.0	18.0	103.5
78	79	78.5	2496.2	154.0	7.0	36.0
79	80	79.5	2546.9	284.0	1.0	65.0
80	81	80.5	2597.5	557.0	14.0	102.0
81	82	81.5	2647.8	648.0	15.0	38.0
84	85	84.5	2797.8	461.0	2.0	27.0
88	89	88.5	2994.0	376.0	9.0	46.0
92	93	92.5	3184.5	263.0	9.0	54.5
97	98	97.5	3416.6	549.0	6.0	48.0
100	101	100.5	3554.7	348.0	2.0	30.0
104	105	104.5	3737.7	363.0	8.0	51.0
108	109	108.5	3919.4	316.0	0.0	27.0
112	113	112.5	4099.9	266.0	13.0	52.0
113	114	113.5	4144.8	510.0	9.0	57.0
116	117	116.5	4279.3	469.0	3.0	23.0
120	121	120.5	4457.8	452.0	20.0	103.0
122	123	122.5	4546.8	200.0	12.0	98.0
124	125	124.5	4635.5	295.0	13.0	70.5
125	126	125.5	4679.7	486.0	14.0	34.5
126	127	126.5	4724.0	295.0	46.0	96.5
127	128	127.5	4768.2	317.0	4.0	41.5
128	129	128.5	4812.3	228.0	11.0	58.5
129	130	129.5	4856.4	426.0	10.0	37.5
130	131	130.5	4900.5	346.0	50.0	77.0
132	133	132.5	4988.5	309.0	4.0	22.0
136	137	136.5	5164.2	462.0	16.0	31.0
140	141	140.5	5339.3	251.0	5.0	39.5
144	145	144.5	5514.2	374.0	28.0	148.5
145	146	145.5	5557.8	421.0	4.0	45.0
148	149	148.5	5688.7	305.0	7.0	56.5
152	153	152.5	5863.1	426.0	4.0	32.0

Upper Depth (cm)	Lower Depth (cm)	Average Depth (cm)	Cal yrs BP	*Picea glacua*	*Picea mariana*	*Picea* undiff
156	157	156.5	6037.4	299.0	3.0	60.5
160	161	160.5	6211.8	419.0	15.0	74.0
161	162	161.5	6255.4	647.0	7.0	87.0
164	165	164.5	6386.4	245.0	1.0	57.5
168	169	168.5	6561.1	407.0	36.0	83.5
170	171	170.5	6648.6	248.0	22.0	90.5
172	173	172.5	6736.2	337.0	18.0	40.5
174	175	174.5	6824.0	300.0	10.0	82.5
176	177	176.5	6911.8	406.0	20.0	79.0
177	178	177.5	6955.8	375.0	8.0	42.0
178	179	178.5	6999.8	281.0	28.0	75.5
179	180	179.5	7043.8	228.0	13.0	50.5
180	181	180.5	7087.9	385.0	9.0	71.5
181	182	181.5	7132.0	136.0	7.0	52.0
184	185	184.5	7264.7	496.0	10.0	24.0
188	189	188.5	7442.2	326.0	6.0	83.0
192	193	192.5	7620.5	248.0	25.0	131.5
193	194	193.5	7665.2	493.0	12.0	48.5
200	201	200.5	7980.2	360.0	17.0	46.0
204	205	204.5	8161.7	215.0	42.0	131.5
208	209	208.5	8344.4	422.0	17.0	53.0
209	210	209.5	8390.3	423.0	6.0	41.0
212	213	212.5	8528.5	460.0	4.0	24.5
216	217	216.5	8714.1	336.0	14.0	35.5
220	221	220.5	8901.2	272.0	23.0	111.5
224	225	224.5	9090.0	271.0	22.0	109.0
225	226	225.5	9137.5	418.0	13.0	23.5
228	229	228.5	9280.6	263.0	12.0	71.0
232	233	232.5	9472.9	645.0	19.0	36.0
236	237	236.5	9667.3	239.0	12.0	34.0
240	241	240.5	9863.7	564.0	28.0	44.5
241	242	241.5	9913.1	146.0	0.0	10.0
242	243	242.5	9962.7	107.0	6.0	25.5
243	244	243.5	10012.4	30.0	1.0	10.5
244	245	244.5	10062.3	125.0	4.0	49.5
245	246	245.5	10112.3	78.0	39.0	23.0
246	247	246.5	10162.4	27.0	7.0	19.0
247	248	247.5	10212.7	24.0	13.0	15.0
248	249	248.5	10263.1	20.0	0.0	1.0
249	250	249.5	10313.7	114.0	81.0	33.0

Average Depth (cm)	Cal yrs BP	*Pinus diploxylon*	*Pinus haploxylon*	*Pinus* undiff	*Populus*	*Juniperus*
0.5		15.0	0.0	1.0	11.0	2.0
1.5	-59.0	18.0	0.0	0.0	14.0	9.0
2.5	-58.1	13.0	0.0	2.0	13.0	0.0
3.5	-56.4	10.0	0.0	4.0	7.0	4.0
4.5	-53.9	19.0	1.0	5.0	22.0	0.0
5.5	-50.6	8.0	0.0	1.5	12.0	9.0
6.5	-46.6	5.0	0.0	1.0	9.0	0.0
7.5	-41.7	5.0	0.0	1.5	8.0	2.0
8.5	-36.0	15.0	0.0	1.5	5.0	1.0
9.5	-29.5	3.0	0.0	0.0	6.0	0.0
10.5	-22.3	11.0	0.0	3.5	8.0	3.0
11.5	-14.2	5.0	1.0	1.5	5.0	10.0
12.5	-5.3	9.0	4.0	0.5	8.0	0.0
13.5	4.3	10.0	0.0	5.0	6.0	0.0
14.5	14.8	10.0	0.0	1.0	24.0	20.0
15.5	26.4	3.0	0.0	0.5	17.0	0.0
16.5	39.4	19.0	0.0	0.5	3.0	1.0
17.5	53.7	12.0	0.0	0.0	7.0	4.0
18.5	69.4	1.0	0.0	0.0	12.0	0.0
19.5	86.2	10.0	2.0	0.0	5.0	4.0
20.5	104.4	3.0	0.0	0.5	13.0	0.0
21.5	123.7	10.0	3.0	0.0	8.0	9.0
22.5	144.3	14.0	5.0	4.5	11.0	0.0
23.5	166.0	3.0	0.0	3.0	20.0	6.0
24.5	188.9	4.0	0.0	0.0	3.0	4.0
25.5	212.9	6.0	0.0	3.0	9.0	0.0
26.5	238.0	6.0	0.0	1.0	6.0	0.0
27.5	264.2	11.0	4.0	2.0	19.0	15.0
28.5	291.5	9.0	0.0	3.0	15.0	44.0
29.5	319.8	5.0	0.0	0.0	2.0	0.0
30.5	349.1	8.0	1.0	2.5	5.0	0.0
31.5	379.4	5.0	0.0	2.5	16.0	13.0
33.5	442.9	7.0	0.0	0.0	4.0	5.0
34.5	476.0	6.0	1.0	2.5	7.0	0.0
35.5	510.1	10.0	3.0	0.0	8.0	0.0
36.5	545.0	6.0	0.0	0.5	6.0	3.0
37.5	580.8	14.0	9.0	1.0	16.0	0.0
38.5	617.4	9.0	5.0	4.0	35.0	0.0
39.5	654.8	24.0	9.0	2.5	10.0	0.0
40.5	693.0	3.0	0.0	0.0	4.0	0.0
41.5	731.9	19.0	12.0	2.0	8.0	14.0
42.5	771.6	29.0	7.0	4.0	22.0	0.0
43.5	812.0	22.0	6.0	4.0	9.0	0.0

Average Depth (cm)	Cal yrs BP	*Pinus diploxylon*	*Pinus haploxylon*	*Pinus* undiff	*Populus*	*Juniperus*
44.5	853.1	8.0	0.0	19.0	11.0	0.0
48.5	1024.0	13.0	0.0	1.5	8.0	16.0
49.5	1068.2	10.0	0.0	0.0	6.0	12.0
56.5	1391.8	6.0	0.0	2.0	2.0	0.0
60.5	1585.8	11.0	3.0	3.0	10.0	19.0
64.5	1784.5	9.0	1.0	0.0	14.0	8.0
65.5	1834.8	7.0	1.0	0.0	7.0	7.0
68.5	1986.5	5.0	0.0	0.0	20.0	0.0
70.5	2088.3	27.0	4.0	6.5	21.0	0.0
72.5	2190.4	7.0	0.0	0.0	6.0	4.0
74.5	2292.5	17.0	1.0	0.0	6.0	0.0
76.5	2394.5	7.0	2.0	3.0	16.0	32.0
77.5	2445.4	33.0	10.0	3.0	22.0	0.0
78.5	2496.2	36.0	5.0	1.5	12.0	0.0
79.5	2546.9	1.0	0.0	0.5	3.0	0.0
80.5	2597.5	5.0	0.0	0.0	11.0	7.0
81.5	2647.8	4.0	0.0	0.0	2.0	0.0
84.5	2797.8	8.0	0.0	2.0	7.0	0.0
88.5	2994.0	4.0	0.0	0.0	5.0	4.0
92.5	3184.5	11.0	0.0	5.5	4.0	0.0
97.5	3416.6	2.0	0.0	0.5	3.0	2.0
100.5	3554.7	6.0	1.0	1.5	15.0	0.0
104.5	3737.7	2.0	0.0	0.0	1.0	4.0
108.5	3919.4	16.0	2.0	2.0	11.0	0.0
112.5	4099.9	3.0	1.0	0.0	11.0	2.0
113.5	4144.8	1.0	0.0	1.0	4.0	3.0
116.5	4279.3	6.0	2.0	2.5	5.0	0.0
120.5	4457.8	0.0	0.0	2.0	7.0	5.0
122.5	4546.8	21.0	7.0	2.5	13.0	0.0
124.5	4635.5	5.0	2.0	0.0	10.0	0.0
125.5	4679.7	4.0	0.0	0.5	4.0	0.0
126.5	4724.0	26.0	5.0	2.0	4.0	0.0
127.5	4768.2	1.0	0.0	0.0	4.0	9.0
128.5	4812.3	0.0	0.0	0.0	18.0	10.0
129.5	4856.4	2.0	0.0	0.0	6.0	2.0
130.5	4900.5	2.0	0.0	0.0	16.0	5.0
132.5	4988.5	4.0	0.0	1.5	5.0	0.0
136.5	5164.2	3.0	0.0	0.0	6.0	6.0
140.5	5339.3	10.0	1.0	3.0	9.0	21.0
144.5	5514.2	5.0	2.0	0.0	3.0	16.0
145.5	5557.8	0.0	0.0	0.0	7.0	0.0
148.5	5688.7	9.0	0.0	0.5	6.0	0.0
152.5	5863.1	4.0	0.0	0.0	5.0	8.0

Average Depth (cm)	Cal yrs BP	*Pinus diploxylon*	*Pinus haploxylon*	*Pinus* undiff	*Populus*	*Juniperus*
156.5	6037.4	3.0	0.0	0.5	7.0	0.0
160.5	6211.8	5.0	0.0	0.5	2.0	0.0
161.5	6255.4	7.0	0.0	1.0	6.0	6.0
164.5	6386.4	7.0	1.0	1.5	13.0	18.0
168.5	6561.1	4.0	0.0	0.5	12.0	4.0
170.5	6648.6	9.0	4.0	3.5	12.0	0.0
172.5	6736.2	9.0	4.0	0.0	7.0	0.0
174.5	6824.0	9.0	3.0	0.0	7.0	0.0
176.5	6911.8	6.0	0.0	0.0	9.0	0.0
177.5	6955.8	1.0	0.0	0.0	8.0	3.0
178.5	6999.8	26.0	3.0	1.0	4.0	0.0
179.5	7043.8	12.0	1.0	2.5	7.0	0.0
180.5	7087.9	8.0	0.0	1.0	6.0	0.0
181.5	7132.0	29.0	9.0	2.5	13.0	30.0
184.5	7264.7	0.0	0.0	0.0	5.0	8.0
188.5	7442.2	7.0	1.0	8.5	4.0	10.0
192.5	7620.5	4.0	0.0	1.0	10.0	6.0
193.5	7665.2	1.0	0.0	0.0	5.0	0.0
200.5	7980.2	4.0	0.0	0.0	15.0	12.0
204.5	8161.7	7.0	4.0	7.0	13.0	0.0
208.5	8344.4	7.0	2.0	2.0	20.0	6.0
209.5	8390.3	4.0	0.0	0.0	20.0	8.0
212.5	8528.5	4.0	0.0	0.0	5.0	0.0
216.5	8714.1	6.0	0.0	0.5	20.0	36.0
220.5	8901.2	7.0	0.0	0.0	7.0	0.0
224.5	9090.0	4.0	0.0	0.0	4.0	11.0
225.5	9137.5	0.0	0.0	0.0	8.0	8.0
228.5	9280.6	9.0	0.0	1.5	6.0	0.0
232.5	9472.9	3.0	0.0	0.0	13.0	19.0
236.5	9667.3	11.0	3.0	5.5	8.0	9.0
240.5	9863.7	6.0	2.0	0.0	9.0	15.0
241.5	9913.1	0.0	0.0	0.0	13.0	12.0
242.5	9962.7	5.0	1.0	0.0	5.0	0.0
243.5	10012.4	1.0	0.0	0.0	10.0	2.0
244.5	10062.3	8.0	0.0	2.5	5.0	0.0
245.5	10112.3	9.0	1.0	1.5	9.0	0.0
246.5	10162.4	24.0	7.0	2.5	13.0	0.0
247.5	10212.7	2.0	0.0	0.0	8.0	17.0
248.5	10263.1	0.0	0.0	0.0	15.0	10.0
249.5	10313.7	34.0	4.0	3.0	22.0	0.0

Average Depth (cm)	Cal yrs BP	*Alnus crispa*	*Alnus rugosa*	*Betula*	*Shepherdia*	Ericaceae	*Salix*
0.5		50.0	14.0	29.0	2.0	2.0	8.0
1.5	-59.0	79.0	6.0	61.0	4.0	3.0	14.0
2.5	-58.1	27.0	1.0	51.0	0.0	5.0	9.0
3.5	-56.4	85.0	8.0	61.0	0.0	15.0	12.0
4.5	-53.9	68.0	14.0	78.0	0.0	3.0	4.0
5.5	-50.6	37.0	3.0	41.0	0.0	8.0	6.0
6.5	-46.6	51.0	2.0	46.0	0.0	5.0	18.0
7.5	-41.7	33.0	2.0	62.0	1.0	3.0	5.0
8.5	-36.0	66.0	8.0	48.0	0.0	8.0	6.0
9.5	-29.5	36.0	3.0	12.0	4.0	3.0	0.0
10.5	-22.3	40.0	3.0	24.0	0.0	6.0	6.0
11.5	-14.2	29.0	3.0	41.0	0.0	5.0	14.0
12.5	-5.3	78.0	8.0	49.0	0.0	5.0	10.0
13.5	4.3	14.0	3.0	29.0	0.0	2.0	10.0
14.5	14.8	36.0	3.0	47.0	0.0	6.0	26.0
15.5	26.4	36.0	4.0	59.0	0.0	1.0	24.0
16.5	39.4	50.0	3.0	41.0	0.0	1.0	3.0
17.5	53.7	76.0	7.0	89.0	2.0	4.0	8.0
18.5	69.4	31.0	1.0	56.0	0.0	1.0	17.0
19.5	86.2	116.0	11.0	54.0	0.0	1.0	33.0
20.5	104.4	30.0	4.0	31.0	0.0	3.0	6.0
21.5	123.7	25.0	10.0	92.0	0.0	1.0	23.0
22.5	144.3	18.0	11.0	23.0	0.0	15.0	11.0
23.5	166.0	17.0	1.0	26.0	0.0	0.0	4.0
24.5	188.9	26.0	0.0	26.0	0.0	0.0	4.0
25.5	212.9	27.0	1.0	44.0	0.0	4.0	4.0
26.5	238.0	2.0	0.0	26.0	0.0	5.0	0.0
27.5	264.2	26.0	5.0	44.0	13.0	14.0	0.0
28.5	291.5	40.0	3.0	55.0	0.0	8.0	28.0
29.5	319.8	32.0	5.0	30.0	0.0	5.0	0.0
30.5	349.1	31.0	4.0	41.0	0.0	10.0	1.0
31.5	379.4	22.0	2.0	41.0	0.0	5.0	1.0
33.5	442.9	119.0	9.0	66.0	2.0	0.0	12.0
34.5	476.0	49.0	0.0	53.0	0.0	11.0	1.0
35.5	510.1	61.0	15.0	62.0	0.0	11.0	38.0
36.5	545.0	29.0	1.0	40.0	0.0	4.0	0.0
37.5	580.8	32.0	8.0	24.0	0.0	2.0	17.0
38.5	617.4	42.0	27.0	48.0	0.0	26.0	28.0
39.5	654.8	22.0	5.0	51.0	0.0	0.0	1.0
40.5	693.0	28.0	2.0	42.0	0.0	2.0	8.0
41.5	731.9	75.0	15.0	33.0	0.0	5.0	13.0
42.5	771.6	27.0	7.0	48.0	0.0	5.0	3.0
43.5	812.0	32.0	4.0	14.0	0.0	13.0	4.0

Average Depth (cm)	Cal yrs BP	*Alnus crispa*	*Alnus rugosa*	*Betula*	*Shepherdia*	Ericaceae	*Salix*
44.5	853.1	52.0	4.0	42.0	0.0	5.0	27.0
48.5	1024.0	51.0	5.0	8.0	2.0	1.0	10.0
49.5	1068.2	64.0	0.0	27.0	2.0	1.0	10.0
56.5	1391.8	42.0	6.0	42.0	0.0	0.0	6.0
60.5	1585.8	22.0	4.0	46.0	0.0	2.0	10.0
64.5	1784.5	52.0	0.0	36.0	0.0	1.0	9.0
65.5	1834.8	48.0	9.0	152.0	4.0	1.0	9.0
68.5	1986.5	27.0	4.0	69.0	0.0	0.0	14.0
70.5	2088.3	38.0	13.0	45.0	17.0	1.0	12.0
72.5	2190.4	21.0	0.0	4.0	1.0	1.0	6.0
74.5	2292.5	38.0	8.0	70.0	0.0	3.0	0.0
76.5	2394.5	18.0	4.0	33.0	0.0	3.0	12.0
77.5	2445.4	25.0	7.0	30.0	0.0	1.0	8.0
78.5	2496.2	57.0	13.0	95.0	0.0	1.0	7.0
79.5	2546.9	53.0	2.0	49.0	0.0	3.0	6.0
80.5	2597.5	44.0	0.0	19.0	0.0	2.0	4.0
81.5	2647.8	47.0	4.0	65.0	0.0	1.0	4.0
84.5	2797.8	20.0	1.0	43.0	14.0	0.0	8.0
88.5	2994.0	24.0	0.0	21.0	11.0	2.0	4.0
92.5	3184.5	11.0	1.0	42.0	0.0	1.0	3.0
97.5	3416.6	43.0	17.0	81.0	0.0	1.0	6.0
100.5	3554.7	44.0	4.0	39.0	0.0	9.0	9.0
104.5	3737.7	49.0	1.0	37.0	0.0	1.0	4.0
108.5	3919.4	32.0	4.0	28.0	0.0	3.0	13.0
112.5	4099.9	59.0	1.0	123.0	0.0	0.0	7.0
113.5	4144.8	41.0	2.0	49.0	2.0	1.0	6.0
116.5	4279.3	35.0	1.0	46.0	7.0	4.0	0.0
120.5	4457.8	50.0	10.0	48.0	0.0	1.0	8.0
122.5	4546.8	35.0	7.0	74.0	0.0	0.0	0.0
124.5	4635.5	49.0	10.0	37.0	0.0	10.0	6.0
125.5	4679.7	20.0	1.0	40.0	5.0	0.0	0.0
126.5	4724.0	15.0	5.0	41.0	0.0	0.0	35.0
127.5	4768.2	29.0	11.0	35.0	0.0	4.0	15.0
128.5	4812.3	65.0	0.0	214.0	1.0	4.0	12.0
129.5	4856.4	37.0	2.0	27.0	0.0	1.0	6.0
130.5	4900.5	32.0	1.0	67.0	0.0	0.0	10.0
132.5	4988.5	63.0	15.0	63.0	0.0	5.0	1.0
136.5	5164.2	37.0	6.0	55.0	0.0	2.0	10.0
140.5	5339.3	71.0	12.0	115.0	0.0	0.0	14.0
144.5	5514.2	26.0	0.0	22.0	3.0	2.0	13.0
145.5	5557.8	47.0	3.0	56.0	0.0	2.0	9.0
148.5	5688.7	36.0	1.0	77.0	11.0	9.0	11.0
152.5	5863.1	43.0	4.0	17.0	0.0	1.0	10.0

Average Depth (cm)	Cal yrs BP	*Alnus crispa*	*Alnus rugosa*	*Betula*	*Shepherdia*	Ericaceae	*Salix*
156.5	6037.4	20.0	9.0	36.0	0.0	4.0	13.0
160.5	6211.8	28.0	0.0	35.0	0.0	5.0	8.0
161.5	6255.4	71.0	2.0	50.0	0.0	2.0	17.0
164.5	6386.4	44.0	7.0	48.0	0.0	1.0	19.0
168.5	6561.1	47.0	0.0	59.0	2.0	2.0	16.0
170.5	6648.6	10.0	1.0	61.0	0.0	0.0	9.0
172.5	6736.2	15.0	4.0	18.0	0.0	3.0	9.0
174.5	6824.0	22.0	2.0	54.0	0.0	6.0	0.0
176.5	6911.8	19.0	0.0	27.0	0.0	2.0	18.0
177.5	6955.8	16.0	0.0	39.0	2.0	1.0	16.0
178.5	6999.8	17.0	1.0	63.0	0.0	3.0	11.0
179.5	7043.8	25.0	1.0	230.0	0.0	10.0	14.0
180.5	7087.9	77.0	14.0	77.0	5.0	3.0	6.0
181.5	7132.0	14.0	6.0	24.0	0.0	7.0	7.0
184.5	7264.7	10.0	0.0	26.0	2.0	2.0	18.0
188.5	7442.2	75.0	10.0	72.0	0.0	10.0	28.0
192.5	7620.5	18.0	3.0	63.0	1.0	2.0	26.0
193.5	7665.2	8.0	0.0	25.0	0.0	0.0	21.0
200.5	7980.2	16.0	8.0	22.0	8.0	1.0	24.0
204.5	8161.7	22.0	5.0	72.0	0.0	6.0	2.0
208.5	8344.4	16.0	1.0	0.0	0.0	1.0	21.0
209.5	8390.3	3.0	0.0	25.0	0.0	0.0	30.0
212.5	8528.5	22.0	2.0	23.0	3.0	0.0	7.0
216.5	8714.1	20.0	1.0	49.0	0.0	2.0	31.0
220.5	8901.2	13.0	4.0	44.0	15.0	10.0	1.0
224.5	9090.0	30.0	4.0	54.0	0.0	2.0	18.0
225.5	9137.5	4.0	0.0	18.0	4.0	0.0	21.0
228.5	9280.6	34.0	6.0	48.0	0.0	2.0	12.0
232.5	9472.9	25.0	2.0	104.0	4.0	0.0	32.0
236.5	9667.3	66.0	20.0	109.0	0.0	5.0	10.0
240.5	9863.7	24.0	0.0	36.0	0.0	1.0	30.0
241.5	9913.1	40.0	7.0	206.0	3.0	0.0	32.0
242.5	9962.7	59.0	26.0	254.0	0.0	0.0	15.0
243.5	10012.4	37.0	7.0	277.0	0.0	1.0	38.0
244.5	10062.3	72.0	15.0	227.0	0.0	6.0	26.0
245.5	10112.3	46.0	16.0	248.0	0.0	8.0	27.0
246.5	10162.4	36.0	14.0	174.0	0.0	9.0	14.0
247.5	10212.7	22.0	5.0	281.0	0.0	1.0	18.0
248.5	10263.1	32.0	4.0	370.0	7.0	0.0	28.0
249.5	10313.7	32.0	15.0	112.0	0.0	12.0	14.0

Average Depth (cm)	Cal yrs BP	*Ambrosia*	*Artemisia*	Asteraceae - Tubuliflorae	Asteraceae - Liguliflorae
0.5		0.0	1.0	1.0	0.0
1.5	-59.0	0.0	0.0	2.0	0.0
2.5	-58.1	0.0	0.0	0.0	0.0
3.5	-56.4	0.0	0.0	0.0	0.0
4.5	-53.9	17.0	15.0	0.0	0.0
5.5	-50.6	0.0	0.0	4.0	0.0
6.5	-46.6	0.0	7.0	2.0	0.0
7.5	-41.7	5.0	14.0	2.0	0.0
8.5	-36.0	0.0	0.0	1.0	0.0
9.5	-29.5	0.0	5.0	0.0	0.0
10.5	-22.3	0.0	4.0	0.0	0.0
11.5	-14.2	0.0	9.0	0.0	0.0
12.5	-5.3	0.0	5.0	0.0	0.0
13.5	4.3	3.0	7.0	0.0	0.0
14.5	14.8	0.0	23.0	1.0	0.0
15.5	26.4	0.0	0.0	0.0	0.0
16.5	39.4	0.0	0.0	5.0	0.0
17.5	53.7	0.0	0.0	0.0	0.0
18.5	69.4	13.0	5.0	0.0	0.0
19.5	86.2	0.0	1.0	0.0	0.0
20.5	104.4	0.0	0.0	10.0	0.0
21.5	123.7	0.0	1.0	0.0	0.0
22.5	144.3	7.0	28.0	8.0	0.0
23.5	166.0	0.0	20.0	0.0	0.0
24.5	188.9	0.0	2.0	0.0	0.0
25.5	212.9	0.0	6.0	0.0	0.0
26.5	238.0	0.0	0.0	0.0	0.0
27.5	264.2	0.0	24.0	0.0	0.0
28.5	291.5	0.0	30.0	0.0	0.0
29.5	319.8	0.0	0.0	0.0	0.0
30.5	349.1	0.0	1.0	14.0	0.0
31.5	379.4	0.0	0.0	0.0	0.0
33.5	442.9	0.0	0.0	8.0	0.0
34.5	476.0	0.0	10.0	5.0	0.0
35.5	510.1	0.0	7.0	1.0	0.0
36.5	545.0	0.0	2.0	7.0	0.0
37.5	580.8	0.0	14.0	0.0	0.0
38.5	617.4	0.0	37.0	2.0	0.0
39.5	654.8	0.0	0.0	0.0	0.0
40.5	693.0	0.0	11.0	8.0	0.0
41.5	731.9	1.0	8.0	11.0	0.0
42.5	771.6	0.0	0.0	1.0	0.0
43.5	812.0	0.0	9.0	25.0	0.0

Average Depth (cm)	Cal yrs BP	*Ambrosia*	*Artemisia*	Asteraceae - Tubuliflorae	Asteraceae - Liguliflorae
44.5	853.1	0.0	10.0	1.0	0.0
48.5	1024.0	0.0	0.0	0.0	0.0
49.5	1068.2	0.0	0.0	0.0	0.0
56.5	1391.8	0.0	1.0	1.0	0.0
60.5	1585.8	0.0	0.0	0.0	0.0
64.5	1784.5	0.0	0.0	1.0	0.0
65.5	1834.8	0.0	7.0	0.0	0.0
68.5	1986.5	0.0	22.0	0.0	0.0
70.5	2088.3	0.0	0.0	15.0	0.0
72.5	2190.4	1.0	0.0	2.0	0.0
74.5	2292.5	0.0	0.0	0.0	0.0
76.5	2394.5	0.0	1.0	1.0	0.0
77.5	2445.4	0.0	12.0	12.0	0.0
78.5	2496.2	0.0	5.0	0.0	0.0
79.5	2546.9	0.0	1.0	0.0	0.0
80.5	2597.5	0.0	0.0	0.0	0.0
81.5	2647.8	0.0	13.0	0.0	0.0
84.5	2797.8	0.0	22.0	0.0	0.0
88.5	2994.0	0.0	3.0	0.0	0.0
92.5	3184.5	5.0	18.0	0.0	0.0
97.5	3416.6	0.0	4.0	0.0	0.0
100.5	3554.7	0.0	19.0	7.0	0.0
104.5	3737.7	0.0	4.0	2.0	0.0
108.5	3919.4	0.0	13.0	0.0	0.0
112.5	4099.9	0.0	5.0	0.0	0.0
113.5	4144.8	0.0	6.0	1.0	0.0
116.5	4279.3	0.0	3.0	14.0	0.0
120.5	4457.8	0.0	2.0	3.0	0.0
122.5	4546.8	0.0	5.0	11.0	0.0
124.5	4635.5	0.0	0.0	1.0	0.0
125.5	4679.7	0.0	4.0	0.0	0.0
126.5	4724.0	10.0	0.0	0.0	0.0
127.5	4768.2	0.0	15.0	0.0	0.0
128.5	4812.3	2.0	5.0	0.0	0.0
129.5	4856.4	0.0	0.0	0.0	0.0
130.5	4900.5	0.0	0.0	0.0	0.0
132.5	4988.5	0.0	2.0	0.0	0.0
136.5	5164.2	0.0	7.0	0.0	0.0
140.5	5339.3	14.0	16.0	2.0	0.0
144.5	5514.2	0.0	0.0	2.0	0.0
145.5	5557.8	0.0	3.0	0.0	0.0
148.5	5688.7	0.0	18.0	1.0	0.0
152.5	5863.1	0.0	3.0	1.0	1.0

Average Depth (cm)	Cal yrs BP	*Ambrosia*	*Artemisia*	Asteraceae - Tubuliflorae	Asteraceae - Liguliflorae
156.5	6037.4	0.0	7.0	0.0	0.0
160.5	6211.8	0.0	0.0	2.0	0.0
161.5	6255.4	0.0	2.0	0.0	0.0
164.5	6386.4	0.0	8.0	5.0	0.0
168.5	6561.1	1.0	1.0	0.0	0.0
170.5	6648.6	0.0	10.0	1.0	0.0
172.5	6736.2	0.0	23.0	0.0	0.0
174.5	6824.0	1.0	11.0	0.0	0.0
176.5	6911.8	0.0	2.0	2.0	0.0
177.5	6955.8	0.0	0.0	0.0	0.0
178.5	6999.8	0.0	1.0	0.0	0.0
179.5	7043.8	0.0	1.0	0.0	0.0
180.5	7087.9	0.0	19.0	5.0	0.0
181.5	7132.0	30.0	15.0	1.0	0.0
184.5	7264.7	0.0	9.0	2.0	0.0
188.5	7442.2	0.0	9.0	2.0	0.0
192.5	7620.5	0.0	5.0	6.0	0.0
193.5	7665.2	0.0	0.0	0.0	0.0
200.5	7980.2	0.0	6.0	4.0	0.0
204.5	8161.7	0.0	25.0	0.0	0.0
208.5	8344.4	0.0	0.0	0.0	0.0
209.5	8390.3	0.0	0.0	0.0	0.0
212.5	8528.5	0.0	13.0	0.0	0.0
216.5	8714.1	0.0	18.0	2.0	0.0
220.5	8901.2	0.0	0.0	0.0	0.0
224.5	9090.0	2.0	1.0	1.0	0.0
225.5	9137.5	0.0	1.0	4.0	0.0
228.5	9280.6	0.0	0.0	0.0	0.0
232.5	9472.9	0.0	2.0	2.0	0.0
236.5	9667.3	0.0	9.0	16.0	0.0
240.5	9863.7	0.0	0.0	0.0	0.0
241.5	9913.1	0.0	0.0	2.0	0.0
242.5	9962.7	23.0	17.0	0.0	0.0
243.5	10012.4	0.0	0.0	0.0	0.0
244.5	10062.3	5.0	12.0	0.0	0.0
245.5	10112.3	25.0	1.0	0.0	0.0
246.5	10162.4	1.0	25.0	32.0	0.0
247.5	10212.7	1.0	31.0	0.0	0.0
248.5	10263.1	0.0	20.0	2.0	0.0
249.5	10313.7	18.0	3.0	0.0	0.0

Average Depth (cm)	Cal yrs BP	Caryophyllaceae	Chenopodiaceae	*Cornus*	*Cornus canadensis*	Cruciferae
0.5		0.0	0.0	0.0	0.0	0.0
1.5	-59.0	1.0	1.0	0.0	0.0	1.0
2.5	-58.1	0.0	0.0	3.0	0.0	0.0
3.5	-56.4	0.0	0.0	0.0	0.0	0.0
4.5	-53.9	0.0	0.0	5.0	0.0	0.0
5.5	-50.6	0.0	0.0	0.0	0.0	0.0
6.5	-46.6	0.0	0.0	1.0	0.0	0.0
7.5	-41.7	0.0	0.0	5.0	0.0	0.0
8.5	-36.0	0.0	0.0	0.0	0.0	0.0
9.5	-29.5	0.0	0.0	0.0	0.0	0.0
10.5	-22.3	0.0	0.0	2.0	0.0	0.0
11.5	-14.2	0.0	0.0	0.0	0.0	0.0
12.5	-5.3	0.0	0.0	0.0	0.0	0.0
13.5	4.3	0.0	0.0	5.0	0.0	0.0
14.5	14.8	0.0	0.0	4.0	0.0	0.0
15.5	26.4	0.0	0.0	0.0	0.0	0.0
16.5	39.4	2.0	0.0	0.0	0.0	2.0
17.5	53.7	0.0	0.0	0.0	1.0	4.0
18.5	69.4	0.0	0.0	0.0	0.0	0.0
19.5	86.2	0.0	0.0	1.0	0.0	0.0
20.5	104.4	0.0	0.0	0.0	0.0	0.0
21.5	123.7	0.0	0.0	9.0	0.0	0.0
22.5	144.3	0.0	0.0	1.0	0.0	0.0
23.5	166.0	0.0	0.0	6.0	0.0	0.0
24.5	188.9	1.0	1.0	0.0	0.0	1.0
25.5	212.9	0.0	0.0	9.0	0.0	0.0
26.5	238.0	0.0	0.0	0.0	0.0	0.0
27.5	264.2	0.0	0.0	16.0	0.0	0.0
28.5	291.5	0.0	0.0	5.0	0.0	0.0
29.5	319.8	0.0	0.0	1.0	0.0	0.0
30.5	349.1	0.0	0.0	0.0	0.0	0.0
31.5	379.4	0.0	0.0	0.0	0.0	0.0
33.5	442.9	1.0	2.0	0.0	1.0	3.0
34.5	476.0	0.0	0.0	0.0	0.0	0.0
35.5	510.1	0.0	0.0	3.0	0.0	0.0
36.5	545.0	0.0	0.0	0.0	0.0	0.0
37.5	580.8	0.0	0.0	7.0	0.0	0.0
38.5	617.4	0.0	0.0	5.0	0.0	0.0
39.5	654.8	0.0	0.0	0.0	0.0	0.0
40.5	693.0	0.0	0.0	0.0	0.0	0.0
41.5	731.9	0.0	0.0	8.0	0.0	0.0
42.5	771.6	0.0	0.0	0.0	0.0	0.0
43.5	812.0	0.0	0.0	6.0	0.0	0.0

Average Depth (cm)	Cal yrs BP	Caryophyllaceae	Chenopodiaceae	*Cornus*	*Cornus canadensis*	Cruciferae
44.5	853.1	0.0	0.0	3.0	0.0	0.0
48.5	1024.0	0.0	0.0	0.0	0.0	1.0
49.5	1068.2	0.0	0.0	0.0	0.0	0.0
56.5	1391.8	0.0	0.0	0.0	0.0	0.0
60.5	1585.8	0.0	0.0	5.0	0.0	0.0
64.5	1784.5	1.0	3.0	0.0	2.0	1.0
65.5	1834.8	0.0	0.0	0.0	0.0	0.0
68.5	1986.5	0.0	0.0	1.0	0.0	0.0
70.5	2088.3	0.0	0.0	9.0	0.0	0.0
72.5	2190.4	1.0	0.0	0.0	0.0	0.0
74.5	2292.5	0.0	0.0	3.0	0.0	0.0
76.5	2394.5	0.0	0.0	9.0	0.0	0.0
77.5	2445.4	0.0	0.0	4.0	0.0	0.0
78.5	2496.2	0.0	0.0	17.0	0.0	0.0
79.5	2546.9	0.0	0.0	0.0	0.0	0.0
80.5	2597.5	3.0	0.0	1.0	0.0	0.0
81.5	2647.8	0.0	0.0	0.0	0.0	0.0
84.5	2797.8	0.0	0.0	2.0	0.0	0.0
88.5	2994.0	0.0	0.0	0.0	0.0	0.0
92.5	3184.5	0.0	0.0	2.0	0.0	0.0
97.5	3416.6	1.0	1.0	0.0	1.0	2.0
100.5	3554.7	0.0	0.0	0.0	0.0	0.0
104.5	3737.7	0.0	0.0	0.0	0.0	0.0
108.5	3919.4	0.0	0.0	7.0	0.0	0.0
112.5	4099.9	1.0	1.0	0.0	0.0	1.0
113.5	4144.8	0.0	0.0	0.0	0.0	0.0
116.5	4279.3	0.0	0.0	0.0	0.0	0.0
120.5	4457.8	0.0	0.0	0.0	0.0	0.0
122.5	4546.8	0.0	0.0	3.0	0.0	0.0
124.5	4635.5	0.0	0.0	5.0	0.0	0.0
125.5	4679.7	0.0	0.0	2.0	0.0	0.0
126.5	4724.0	0.0	0.0	22.0	0.0	0.0
127.5	4768.2	0.0	0.0	1.0	0.0	0.0
128.5	4812.3	2.0	0.0	0.0	0.0	1.0
129.5	4856.4	0.0	0.0	0.0	0.0	0.0
130.5	4900.5	0.0	0.0	3.0	0.0	0.0
132.5	4988.5	0.0	0.0	0.0	0.0	0.0
136.5	5164.2	0.0	1.0	0.0	1.0	0.0
140.5	5339.3	0.0	0.0	0.0	0.0	0.0
144.5	5514.2	1.0	0.0	0.0	0.0	0.0
145.5	5557.8	0.0	0.0	0.0	0.0	0.0
148.5	5688.7	0.0	0.0	11.0	0.0	0.0
152.5	5863.1	0.0	0.0	0.0	0.0	0.0

Average Depth (cm)	Cal yrs BP	Caryophyllaceae	Chenopodiaceae	*Cornus*	*Cornus canadensis*	Cruciferae
156.5	6037.4	0.0	0.0	3.0	0.0	0.0
160.5	6211.8	2.0	0.0	0.0	0.0	0.0
161.5	6255.4	0.0	2.0	0.0	0.0	2.0
164.5	6386.4	0.0	0.0	0.0	0.0	0.0
168.5	6561.1	1.0	0.0	0.0	0.0	0.0
170.5	6648.6	0.0	0.0	2.0	0.0	0.0
172.5	6736.2	0.0	0.0	4.0	0.0	0.0
174.5	6824.0	0.0	0.0	6.0	0.0	0.0
176.5	6911.8	0.0	0.0	0.0	0.0	2.0
177.5	6955.8	4.0	0.0	0.0	0.0	0.0
178.5	6999.8	0.0	0.0	4.0	0.0	0.0
179.5	7043.8	0.0	0.0	1.0	0.0	0.0
180.5	7087.9	0.0	0.0	11.0	0.0	0.0
181.5	7132.0	0.0	0.0	3.0	0.0	0.0
184.5	7264.7	1.0	2.0	0.0	0.0	0.0
188.5	7442.2	0.0	0.0	23.0	0.0	0.0
192.5	7620.5	1.0	4.0	1.0	0.0	1.0
193.5	7665.2	0.0	0.0	0.0	0.0	0.0
200.5	7980.2	1.0	1.0	0.0	1.0	0.0
204.5	8161.7	0.0	0.0	6.0	0.0	0.0
208.5	8344.4	0.0	0.0	0.0	0.0	0.0
209.5	8390.3	1.0	0.0	0.0	0.0	1.0
212.5	8528.5	0.0	0.0	2.0	0.0	0.0
216.5	8714.1	2.0	2.0	0.0	2.0	0.0
220.5	8901.2	0.0	0.0	6.0	0.0	0.0
224.5	9090.0	4.0	3.0	0.0	0.0	0.0
225.5	9137.5	0.0	0.0	0.0	0.0	0.0
228.5	9280.6	0.0	0.0	3.0	0.0	0.0
232.5	9472.9	1.0	1.0	0.0	0.0	1.0
236.5	9667.3	0.0	0.0	10.0	0.0	0.0
240.5	9863.7	0.0	0.0	0.0	0.0	0.0
241.5	9913.1	1.0	0.0	0.0	0.0	0.0
242.5	9962.7	0.0	0.0	3.0	0.0	0.0
243.5	10012.4	0.0	0.0	1.0	0.0	0.0
244.5	10062.3	0.0	0.0	4.0	0.0	0.0
245.5	10112.3	0.0	0.0	16.0	0.0	0.0
246.5	10162.4	0.0	0.0	5.0	0.0	0.0
247.5	10212.7	0.0	0.0	0.0	0.0	0.0
248.5	10263.1	0.0	0.0	0.0	0.0	0.0
249.5	10313.7	0.0	0.0	3.0	0.0	0.0

Average Depth (cm)	Cal yrs BP	Cyperaceae	*Dryas*	*Epilobium*	*Galium*	Poaceae	*Polygonum viviparum*
0.5		56.0	0.0	0.0	0.0	16.0	0.0
1.5	-59.0	28.0	0.0	0.0	0.0	24.0	0.0
2.5	-58.1	25.0	0.0	0.0	0.0	0.0	1.0
3.5	-56.4	28.0	0.0	0.0	0.0	35.0	0.0
4.5	-53.9	17.0	0.0	0.0	0.0	5.0	9.0
5.5	-50.6	29.0	3.0	0.0	0.0	9.0	0.0
6.5	-46.6	32.0	0.0	0.0	0.0	3.0	0.0
7.5	-41.7	16.0	0.0	0.0	0.0	0.0	0.0
8.5	-36.0	18.0	0.0	0.0	0.0	2.0	0.0
9.5	-29.5	17.0	0.0	0.0	0.0	3.0	0.0
10.5	-22.3	7.0	0.0	0.0	0.0	0.0	3.0
11.5	-14.2	23.0	0.0	0.0	0.0	19.0	0.0
12.5	-5.3	18.0	0.0	0.0	0.0	7.0	0.0
13.5	4.3	15.0	0.0	0.0	0.0	0.0	0.0
14.5	14.8	16.0	0.0	0.0	0.0	10.0	0.0
15.5	26.4	15.0	0.0	0.0	0.0	22.0	0.0
16.5	39.4	23.0	2.0	0.0	1.0	5.0	0.0
17.5	53.7	22.0	0.0	2.0	0.0	0.0	0.0
18.5	69.4	23.0	0.0	3.0	0.0	19.0	1.0
19.5	86.2	17.0	0.0	0.0	0.0	12.0	0.0
20.5	104.4	8.0	4.0	7.0	0.0	0.0	0.0
21.5	123.7	25.0	4.0	0.0	0.0	31.0	3.0
22.5	144.3	20.0	13.0	0.0	0.0	1.0	17.0
23.5	166.0	13.0	0.0	0.0	0.0	5.0	0.0
24.5	188.9	1.0	0.0	0.0	0.0	3.0	0.0
25.5	212.9	8.0	0.0	0.0	0.0	0.0	3.0
26.5	238.0	16.0	0.0	0.0	0.0	3.0	0.0
27.5	264.2	26.0	0.0	0.0	0.0	9.0	0.0
28.5	291.5	16.0	0.0	0.0	0.0	22.0	0.0
29.5	319.8	12.0	0.0	0.0	0.0	5.0	0.0
30.5	349.1	9.0	0.0	0.0	0.0	12.0	0.0
31.5	379.4	25.0	0.0	0.0	0.0	6.0	0.0
33.5	442.9	14.0	0.0	0.0	0.0	3.0	0.0
34.5	476.0	19.0	0.0	0.0	0.0	11.0	0.0
35.5	510.1	24.0	6.0	0.0	0.0	9.0	0.0
36.5	545.0	4.0	0.0	0.0	0.0	0.0	0.0
37.5	580.8	24.0	6.0	0.0	0.0	7.0	1.0
38.5	617.4	28.0	0.0	0.0	0.0	0.0	3.0
39.5	654.8	21.0	4.0	0.0	0.0	1.0	0.0
40.5	693.0	14.0	0.0	2.0	0.0	11.0	0.0
41.5	731.9	18.0	1.0	0.0	0.0	3.0	0.0
42.5	771.6	34.0	0.0	0.0	0.0	3.0	0.0
43.5	812.0	36.0	0.0	0.0	0.0	10.0	0.0

Average Depth (cm)	Cal yrs BP	Cyperaceae	*Dryas*	*Epilobium*	*Galium*	Poaceae	*Polygonum viviparum*
44.5	853.1	18.0	0.0	0.0	0.0	9.0	0.0
48.5	1024.0	44.0	0.0	0.0	1.0	16.0	0.0
49.5	1068.2	16.0	0.0	0.0	0.0	0.0	0.0
56.5	1391.8	7.0	0.0	0.0	0.0	2.0	0.0
60.5	1585.8	30.0	0.0	0.0	0.0	0.0	0.0
64.5	1784.5	4.0	0.0	0.0	2.0	2.0	0.0
65.5	1834.8	16.0	0.0	0.0	0.0	17.0	0.0
68.5	1986.5	23.0	12.0	0.0	0.0	3.0	1.0
70.5	2088.3	22.0	15.0	0.0	0.0	13.0	0.0
72.5	2190.4	11.0	0.0	0.0	0.0	0.0	0.0
74.5	2292.5	35.0	1.0	0.0	0.0	29.0	0.0
76.5	2394.5	20.0	15.0	0.0	0.0	0.0	6.0
77.5	2445.4	31.0	5.0	0.0	0.0	5.0	0.0
78.5	2496.2	30.0	0.0	2.0	0.0	34.0	0.0
79.5	2546.9	20.0	0.0	0.0	0.0	34.0	0.0
80.5	2597.5	5.0	0.0	0.0	0.0	0.0	0.0
81.5	2647.8	11.0	0.0	2.0	0.0	1.0	0.0
84.5	2797.8	17.0	5.0	17.0	0.0	3.0	0.0
88.5	2994.0	6.0	0.0	0.0	0.0	8.0	0.0
92.5	3184.5	18.0	0.0	0.0	0.0	0.0	2.0
97.5	3416.6	25.0	0.0	2.0	1.0	8.0	0.0
100.5	3554.7	23.0	0.0	0.0	0.0	0.0	0.0
104.5	3737.7	3.0	0.0	1.0	0.0	2.0	0.0
108.5	3919.4	11.0	3.0	0.0	0.0	13.0	2.0
112.5	4099.9	11.0	0.0	0.0	0.0	9.0	0.0
113.5	4144.8	5.0	0.0	2.0	0.0	0.0	3.0
116.5	4279.3	9.0	0.0	0.0	0.0	0.0	0.0
120.5	4457.8	10.0	0.0	0.0	0.0	4.0	0.0
122.5	4546.8	10.0	0.0	2.0	0.0	0.0	0.0
124.5	4635.5	16.0	5.0	3.0	0.0	9.0	0.0
125.5	4679.7	3.0	0.0	0.0	0.0	0.0	0.0
126.5	4724.0	23.0	5.0	0.0	0.0	16.0	0.0
127.5	4768.2	18.0	0.0	0.0	0.0	10.0	0.0
128.5	4812.3	11.0	0.0	0.0	0.0	19.0	0.0
129.5	4856.4	8.0	0.0	0.0	0.0	3.0	0.0
130.5	4900.5	33.0	0.0	0.0	0.0	21.0	0.0
132.5	4988.5	17.0	0.0	0.0	0.0	0.0	1.0
136.5	5164.2	4.0	0.0	0.0	1.0	5.0	2.0
140.5	5339.3	16.0	0.0	0.0	0.0	6.0	0.0
144.5	5514.2	6.0	0.0	0.0	0.0	3.0	0.0
145.5	5557.8	14.0	0.0	0.0	0.0	4.0	0.0
148.5	5688.7	5.0	4.0	0.0	0.0	0.0	0.0
152.5	5863.1	4.0	0.0	0.0	0.0	2.0	0.0

Average Depth (cm)	Cal yrs BP	Cyperaceae	*Dryas*	*Epilobium*	*Galium*	Poaceae	*Polygonum viviparum*
156.5	6037.4	0.0	0.0	0.0	0.0	16.0	0.0
160.5	6211.8	2.0	0.0	0.0	0.0	5.0	0.0
161.5	6255.4	15.0	0.0	14.0	0.0	14.0	0.0
164.5	6386.4	12.0	0.0	0.0	0.0	0.0	3.0
168.5	6561.1	3.0	0.0	0.0	0.0	7.0	0.0
170.5	6648.6	22.0	3.0	0.0	0.0	6.0	1.0
172.5	6736.2	1.0	0.0	0.0	0.0	15.0	6.0
174.5	6824.0	18.0	1.0	0.0	0.0	19.0	0.0
176.5	6911.8	5.0	0.0	0.0	1.0	2.0	0.0
177.5	6955.8	12.0	0.0	2.0	0.0	6.0	3.0
178.5	6999.8	18.0	1.0	0.0	0.0	23.0	1.0
179.5	7043.8	17.0	3.0	0.0	0.0	8.0	2.0
180.5	7087.9	15.0	0.0	0.0	0.0	3.0	1.0
181.5	7132.0	4.0	19.0	0.0	0.0	21.0	0.0
184.5	7264.7	8.0	0.0	0.0	0.0	0.0	0.0
188.5	7442.2	7.0	0.0	0.0	0.0	0.0	0.0
192.5	7620.5	22.0	1.0	0.0	0.0	23.0	0.0
193.5	7665.2	3.0	0.0	0.0	0.0	2.0	0.0
200.5	7980.2	0.0	0.0	1.0	0.0	1.0	0.0
204.5	8161.7	14.0	7.0	0.0	0.0	4.0	3.0
208.5	8344.4	22.0	0.0	0.0	0.0	1.0	0.0
209.5	8390.3	2.0	0.0	0.0	2.0	4.0	0.0
212.5	8528.5	1.0	3.0	0.0	0.0	0.0	0.0
216.5	8714.1	28.0	0.0	0.0	0.0	1.0	0.0
220.5	8901.2	18.0	8.0	0.0	0.0	6.0	0.0
224.5	9090.0	24.0	0.0	0.0	0.0	24.0	0.0
225.5	9137.5	4.0	0.0	0.0	0.0	6.0	0.0
228.5	9280.6	12.0	7.0	3.0	0.0	2.0	0.0
232.5	9472.9	0.0	0.0	0.0	0.0	3.0	0.0
236.5	9667.3	3.0	10.0	0.0	0.0	7.0	3.0
240.5	9863.7	19.0	0.0	0.0	0.0	14.0	0.0
241.5	9913.1	27.0	0.0	0.0	0.0	26.0	0.0
242.5	9962.7	31.0	7.0	0.0	0.0	41.0	0.0
243.5	10012.4	19.0	2.0	0.0	0.0	31.0	0.0
244.5	10062.3	6.0	4.0	0.0	0.0	3.0	0.0
245.5	10112.3	9.0	8.0	0.0	0.0	3.0	0.0
246.5	10162.4	9.0	28.0	0.0	0.0	20.0	0.0
247.5	10212.7	17.0	2.0	0.0	0.0	24.0	0.0
248.5	10263.1	20.0	0.0	0.0	0.0	5.0	0.0
249.5	10313.7	9.0	11.0	0.0	0.0	14.0	8.0

Average Depth (cm)	Cal yrs BP	*Potentilla*	*Ranunculus*	Rosaceae	Saxifragaceae	*Saxifraga oppositifolia*
0.5		1.0	0.0	0.0	0.0	0.0
1.5	-59.0	0.0	0.0	1.0	0.0	0.0
2.5	-58.1	7.0	0.0	0.0	0.0	0.0
3.5	-56.4	0.0	0.0	0.0	0.0	0.0
4.5	-53.9	0.0	0.0	0.0	0.0	0.0
5.5	-50.6	0.0	0.0	0.0	0.0	0.0
6.5	-46.6	0.0	0.0	0.0	0.0	0.0
7.5	-41.7	0.0	0.0	0.0	0.0	0.0
8.5	-36.0	0.0	0.0	0.0	0.0	0.0
9.5	-29.5	0.0	0.0	0.0	0.0	0.0
10.5	-22.3	0.0	0.0	0.0	0.0	0.0
11.5	-14.2	0.0	0.0	0.0	0.0	0.0
12.5	-5.3	0.0	0.0	0.0	0.0	0.0
13.5	4.3	0.0	0.0	0.0	0.0	0.0
14.5	14.8	0.0	0.0	0.0	0.0	0.0
15.5	26.4	0.0	0.0	0.0	0.0	0.0
16.5	39.4	0.0	0.0	1.0	0.0	0.0
17.5	53.7	0.0	0.0	0.0	0.0	0.0
18.5	69.4	0.0	0.0	0.0	0.0	0.0
19.5	86.2	0.0	0.0	0.0	0.0	0.0
20.5	104.4	4.0	0.0	0.0	0.0	0.0
21.5	123.7	0.0	2.0	0.0	0.0	0.0
22.5	144.3	0.0	0.0	0.0	0.0	0.0
23.5	166.0	0.0	0.0	0.0	0.0	0.0
24.5	188.9	0.0	0.0	0.0	0.0	0.0
25.5	212.9	0.0	0.0	0.0	0.0	0.0
26.5	238.0	0.0	0.0	0.0	0.0	0.0
27.5	264.2	0.0	0.0	0.0	0.0	0.0
28.5	291.5	0.0	0.0	0.0	0.0	0.0
29.5	319.8	0.0	0.0	0.0	0.0	0.0
30.5	349.1	0.0	0.0	0.0	0.0	0.0
31.5	379.4	1.0	3.0	0.0	0.0	0.0
33.5	442.9	0.0	1.0	1.0	0.0	1.0
34.5	476.0	0.0	0.0	0.0	0.0	0.0
35.5	510.1	1.0	0.0	0.0	0.0	0.0
36.5	545.0	0.0	0.0	0.0	0.0	0.0
37.5	580.8	8.0	0.0	0.0	0.0	0.0
38.5	617.4	21.0	12.0	0.0	0.0	0.0
39.5	654.8	1.0	0.0	0.0	0.0	0.0
40.5	693.0	0.0	0.0	0.0	0.0	0.0
41.5	731.9	8.0	0.0	0.0	0.0	0.0
42.5	771.6	0.0	0.0	0.0	0.0	0.0
43.5	812.0	0.0	0.0	0.0	0.0	0.0

Average Depth (cm)	Cal yrs BP	*Potentilla*	*Ranunculus*	Rosaceae	Saxifragaceae	*Saxifraga oppositifolia*
44.5	853.1	0.0	0.0	0.0	0.0	0.0
48.5	1024.0	0.0	0.0	1.0	0.0	0.0
49.5	1068.2	0.0	0.0	0.0	0.0	0.0
56.5	1391.8	0.0	0.0	0.0	0.0	0.0
60.5	1585.8	0.0	0.0	0.0	0.0	0.0
64.5	1784.5	0.0	1.0	1.0	0.0	1.0
65.5	1834.8	0.0	0.0	0.0	0.0	1.0
68.5	1986.5	0.0	0.0	0.0	0.0	0.0
70.5	2088.3	0.0	0.0	3.0	0.0	0.0
72.5	2190.4	0.0	1.0	1.0	0.0	0.0
74.5	2292.5	0.0	0.0	0.0	0.0	0.0
76.5	2394.5	0.0	0.0	0.0	0.0	0.0
77.5	2445.4	20.0	0.0	0.0	0.0	0.0
78.5	2496.2	0.0	0.0	0.0	0.0	0.0
79.5	2546.9	0.0	0.0	0.0	0.0	0.0
80.5	2597.5	0.0	0.0	1.0	0.0	0.0
81.5	2647.8	0.0	0.0	0.0	0.0	0.0
84.5	2797.8	0.0	0.0	0.0	0.0	0.0
88.5	2994.0	0.0	0.0	0.0	0.0	0.0
92.5	3184.5	14.0	0.0	0.0	0.0	0.0
97.5	3416.6	0.0	0.0	0.0	0.0	1.0
100.5	3554.7	0.0	0.0	0.0	0.0	0.0
104.5	3737.7	1.0	1.0	1.0	0.0	0.0
108.5	3919.4	0.0	0.0	0.0	0.0	0.0
112.5	4099.9	0.0	2.0	1.0	0.0	1.0
113.5	4144.8	0.0	0.0	0.0	0.0	0.0
116.5	4279.3	3.0	0.0	0.0	0.0	0.0
120.5	4457.8	0.0	0.0	0.0	0.0	0.0
122.5	4546.8	3.0	0.0	0.0	0.0	0.0
124.5	4635.5	0.0	0.0	0.0	0.0	0.0
125.5	4679.7	0.0	0.0	0.0	0.0	0.0
126.5	4724.0	17.0	0.0	0.0	0.0	0.0
127.5	4768.2	0.0	0.0	0.0	0.0	0.0
128.5	4812.3	0.0	0.0	1.0	0.0	1.0
129.5	4856.4	0.0	0.0	0.0	0.0	0.0
130.5	4900.5	0.0	0.0	1.0	0.0	0.0
132.5	4988.5	0.0	0.0	0.0	0.0	0.0
136.5	5164.2	0.0	0.0	2.0	0.0	0.0
140.5	5339.3	0.0	0.0	0.0	0.0	0.0
144.5	5514.2	0.0	0.0	0.0	0.0	0.0
145.5	5557.8	0.0	0.0	1.0	0.0	0.0
148.5	5688.7	0.0	0.0	0.0	0.0	0.0
152.5	5863.1	0.0	0.0	1.0	0.0	1.0

Average Depth (cm)	Cal yrs BP	*Potentilla*	*Ranunculus*	Rosaceae	Saxifragaceae	*Saxifraga oppositifolia*
156.5	6037.4	8.0	0.0	0.0	0.0	0.0
160.5	6211.8	2.0	0.0	0.0	0.0	0.0
161.5	6255.4	0.0	0.0	1.0	0.0	1.0
164.5	6386.4	0.0	0.0	0.0	0.0	0.0
168.5	6561.1	0.0	1.0	2.0	0.0	1.0
170.5	6648.6	0.0	0.0	0.0	0.0	0.0
172.5	6736.2	0.0	0.0	0.0	0.0	0.0
174.5	6824.0	0.0	0.0	0.0	0.0	0.0
176.5	6911.8	0.0	0.0	0.0	0.0	0.0
177.5	6955.8	0.0	0.0	1.0	0.0	0.0
178.5	6999.8	0.0	0.0	0.0	0.0	3.0
179.5	7043.8	0.0	0.0	0.0	0.0	0.0
180.5	7087.9	0.0	0.0	0.0	0.0	0.0
181.5	7132.0	0.0	0.0	0.0	0.0	0.0
184.5	7264.7	0.0	0.0	0.0	0.0	0.0
188.5	7442.2	0.0	0.0	0.0	0.0	0.0
192.5	7620.5	0.0	0.0	1.0	0.0	1.0
193.5	7665.2	0.0	2.0	0.0	0.0	0.0
200.5	7980.2	0.0	0.0	2.0	0.0	0.0
204.5	8161.7	0.0	0.0	0.0	0.0	0.0
208.5	8344.4	1.0	0.0	0.0	2.0	0.0
209.5	8390.3	0.0	0.0	1.0	0.0	0.0
212.5	8528.5	0.0	0.0	0.0	0.0	0.0
216.5	8714.1	0.0	0.0	0.0	0.0	1.0
220.5	8901.2	6.0	11.0	0.0	0.0	0.0
224.5	9090.0	0.0	0.0	1.0	0.0	0.0
225.5	9137.5	0.0	0.0	2.0	0.0	0.0
228.5	9280.6	0.0	0.0	0.0	0.0	0.0
232.5	9472.9	1.0	0.0	1.0	0.0	1.0
236.5	9667.3	8.0	0.0	0.0	0.0	0.0
240.5	9863.7	2.0	0.0	0.0	0.0	0.0
241.5	9913.1	0.0	0.0	0.0	0.0	0.0
242.5	9962.7	5.0	0.0	0.0	0.0	0.0
243.5	10012.4	0.0	0.0	0.0	0.0	0.0
244.5	10062.3	0.0	0.0	0.0	0.0	0.0
245.5	10112.3	5.0	0.0	0.0	0.0	0.0
246.5	10162.4	6.0	0.0	0.0	0.0	0.0
247.5	10212.7	0.0	0.0	0.0	0.0	0.0
248.5	10263.1	0.0	0.0	0.0	0.0	0.0
249.5	10313.7	6.0	0.0	0.0	0.0	0.0

Average Depth (cm)	Cal yrs BP	*Thalictrum*	Umbelliferae	Polypodiaceae	*Pteridium*	*Lycopodium*
0.5		0.0	0.0	1.0	0.0	1.0
1.5	-59.0	0.0	0.0	1.0	0.0	7.0
2.5	-58.1	0.0	0.0	0.0	0.0	12.0
3.5	-56.4	0.0	0.0	6.0	0.0	18.0
4.5	-53.9	0.0	0.0	0.0	0.0	7.0
5.5	-50.6	0.0	0.0	10.0	0.0	4.0
6.5	-46.6	0.0	0.0	10.0	0.0	6.0
7.5	-41.7	0.0	0.0	16.0	0.0	1.0
8.5	-36.0	6.0	0.0	2.0	0.0	1.0
9.5	-29.5	0.0	0.0	6.0	0.0	5.0
10.5	-22.3	2.0	0.0	0.0	0.0	3.0
11.5	-14.2	0.0	0.0	0.0	0.0	6.0
12.5	-5.3	0.0	0.0	23.0	0.0	13.0
13.5	4.3	0.0	0.0	5.0	20.0	10.0
14.5	14.8	9.0	0.0	0.0	0.0	3.0
15.5	26.4	0.0	0.0	2.0	0.0	1.0
16.5	39.4	0.0	0.0	4.0	0.0	2.0
17.5	53.7	0.0	0.0	5.0	0.0	5.0
18.5	69.4	0.0	0.0	0.0	0.0	6.0
19.5	86.2	0.0	0.0	7.0	0.0	7.0
20.5	104.4	0.0	0.0	7.0	0.0	4.0
21.5	123.7	1.0	0.0	5.0	0.0	5.0
22.5	144.3	0.0	0.0	0.0	0.0	0.0
23.5	166.0	5.0	0.0	0.0	0.0	0.0
24.5	188.9	2.0	1.0	0.0	0.0	0.0
25.5	212.9	4.0	0.0	0.0	0.0	4.0
26.5	238.0	0.0	0.0	3.0	0.0	3.0
27.5	264.2	0.0	0.0	0.0	0.0	13.0
28.5	291.5	0.0	0.0	14.0	0.0	17.0
29.5	319.8	23.0	0.0	0.0	0.0	6.0
30.5	349.1	6.0	0.0	0.0	0.0	10.0
31.5	379.4	0.0	0.0	0.0	0.0	6.0
33.5	442.9	1.0	0.0	1.0	2.0	1.0
34.5	476.0	4.0	0.0	0.0	0.0	10.0
35.5	510.1	0.0	0.0	0.0	0.0	17.0
36.5	545.0	0.0	0.0	0.0	0.0	0.0
37.5	580.8	23.0	0.0	0.0	0.0	36.0
38.5	617.4	0.0	0.0	4.0	0.0	34.0
39.5	654.8	0.0	0.0	0.0	0.0	15.0
40.5	693.0	9.0	1.0	3.0	0.0	4.0
41.5	731.9	0.0	0.0	0.0	0.0	9.0
42.5	771.6	0.0	0.0	0.0	0.0	10.0
43.5	812.0	0.0	0.0	0.0	0.0	38.0

Average Depth (cm)	Cal yrs BP	*Thalictrum*	Umbelliferae	Polypodiaceae	*Pteridium*	*Lycopodium*
44.5	853.1	7.0	0.0	0.0	0.0	12.0
48.5	1024.0	2.0	1.0	4.0	0.0	5.0
49.5	1068.2	0.0	0.0	3.0	0.0	1.0
56.5	1391.8	0.0	0.0	0.0	0.0	0.0
60.5	1585.8	0.0	0.0	0.0	0.0	25.0
64.5	1784.5	0.0	0.0	1.0	0.0	3.0
65.5	1834.8	0.0	0.0	0.0	0.0	0.0
68.5	1986.5	4.0	0.0	7.0	0.0	2.0
70.5	2088.3	0.0	0.0	2.0	0.0	18.0
72.5	2190.4	0.0	0.0	2.0	0.0	2.0
74.5	2292.5	5.0	0.0	4.0	0.0	10.0
76.5	2394.5	0.0	0.0	0.0	0.0	28.0
77.5	2445.4	0.0	0.0	0.0	0.0	39.0
78.5	2496.2	7.0	0.0	0.0	0.0	2.0
79.5	2546.9	0.0	0.0	7.0	0.0	5.0
80.5	2597.5	0.0	2.0	3.0	0.0	2.0
81.5	2647.8	0.0	0.0	0.0	0.0	2.0
84.5	2797.8	0.0	0.0	0.0	0.0	3.0
88.5	2994.0	3.0	0.0	0.0	0.0	3.0
92.5	3184.5	0.0	0.0	0.0	0.0	12.0
97.5	3416.6	1.0	0.0	3.0	0.0	3.0
100.5	3554.7	0.0	0.0	9.0	0.0	15.0
104.5	3737.7	1.0	0.0	3.0	0.0	6.0
108.5	3919.4	0.0	0.0	0.0	0.0	14.0
112.5	4099.9	0.0	1.0	3.0	0.0	5.0
113.5	4144.8	0.0	0.0	0.0	0.0	0.0
116.5	4279.3	0.0	0.0	0.0	0.0	8.0
120.5	4457.8	1.0	0.0	0.0	0.0	3.0
122.5	4546.8	0.0	0.0	0.0	6.0	18.0
124.5	4635.5	0.0	0.0	0.0	0.0	10.0
125.5	4679.7	0.0	0.0	0.0	0.0	9.0
126.5	4724.0	0.0	0.0	0.0	0.0	16.0
127.5	4768.2	0.0	0.0	0.0	0.0	2.0
128.5	4812.3	0.0	2.0	1.0	0.0	9.0
129.5	4856.4	0.0	0.0	0.0	0.0	1.0
130.5	4900.5	0.0	0.0	0.0	0.0	3.0
132.5	4988.5	0.0	0.0	0.0	0.0	25.0
136.5	5164.2	2.0	0.0	0.0	0.0	0.0
140.5	5339.3	0.0	0.0	0.0	0.0	5.0
144.5	5514.2	1.0	0.0	1.0	0.0	0.0
145.5	5557.8	0.0	0.0	0.0	0.0	0.0
148.5	5688.7	0.0	0.0	0.0	0.0	8.0
152.5	5863.1	1.0	1.0	0.0	0.0	0.0

Average Depth (cm)	Cal yrs BP	*Thalictrum*	Umbelliferae	Polypodiaceae	*Pteridium*	*Lycopodium*
156.5	6037.4	7.0	0.0	0.0	0.0	5.0
160.5	6211.8	0.0	0.0	2.0	0.0	3.0
161.5	6255.4	0.0	0.0	3.0	0.0	5.0
164.5	6386.4	0.0	0.0	0.0	0.0	6.0
168.5	6561.1	0.0	0.0	1.0	0.0	3.0
170.5	6648.6	0.0	0.0	0.0	0.0	37.0
172.5	6736.2	0.0	0.0	0.0	0.0	19.0
174.5	6824.0	0.0	0.0	0.0	0.0	10.0
176.5	6911.8	0.0	0.0	0.0	0.0	2.0
177.5	6955.8	1.0	0.0	0.0	0.0	0.0
178.5	6999.8	0.0	0.0	1.0	0.0	6.0
179.5	7043.8	0.0	0.0	0.0	0.0	5.0
180.5	7087.9	0.0	0.0	0.0	0.0	12.0
181.5	7132.0	0.0	0.0	0.0	0.0	25.0
184.5	7264.7	0.0	0.0	4.0	0.0	4.0
188.5	7442.2	0.0	0.0	9.0	0.0	11.0
192.5	7620.5	0.0	1.0	2.0	0.0	3.0
193.5	7665.2	0.0	0.0	0.0	0.0	0.0
200.5	7980.2	0.0	0.0	0.0	0.0	2.0
204.5	8161.7	0.0	0.0	0.0	0.0	25.0
208.5	8344.4	0.0	0.0	1.0	0.0	0.0
209.5	8390.3	0.0	3.0	8.0	1.0	2.0
212.5	8528.5	0.0	0.0	0.0	0.0	5.0
216.5	8714.1	4.0	0.0	11.0	0.0	1.0
220.5	8901.2	0.0	0.0	0.0	0.0	14.0
224.5	9090.0	0.0	0.0	11.0	0.0	2.0
225.5	9137.5	0.0	0.0	4.0	0.0	0.0
228.5	9280.6	0.0	0.0	0.0	0.0	7.0
232.5	9472.9	0.0	0.0	3.0	0.0	0.0
236.5	9667.3	27.0	0.0	0.0	0.0	19.0
240.5	9863.7	6.0	0.0	5.0	0.0	0.0
241.5	9913.1	0.0	0.0	7.0	0.0	4.0
242.5	9962.7	0.0	0.0	0.0	0.0	15.0
243.5	10012.4	0.0	0.0	0.0	0.0	6.0
244.5	10062.3	1.0	0.0	10.0	0.0	8.0
245.5	10112.3	0.0	0.0	0.0	0.0	19.0
246.5	10162.4	0.0	0.0	2.0	0.0	50.0
247.5	10212.7	0.0	0.0	4.0	0.0	6.0
248.5	10263.1	5.0	0.0	4.0	0.0	0.0
249.5	10313.7	0.0	0.0	0.0	0.0	32.0

Average Depth (cm)	Cal yrs BP	*Sphagnum*	*Equisetum*	*Myriophyllum*	*Potamogeton*	*Typha*
0.5		1.0	2.0	122.0	0.0	0.0
1.5	-59.0	1.0	0.0	61.0	3.0	0.0
2.5	-58.1	0.0	0.0	28.0	0.0	0.0
3.5	-56.4	0.0	0.0	8.0	0.0	0.0
4.5	-53.9	15.0	0.0	25.0	0.0	0.0
5.5	-50.6	0.0	0.0	28.0	0.0	0.0
6.5	-46.6	1.0	0.0	31.0	0.0	0.0
7.5	-41.7	0.0	4.0	38.0	0.0	0.0
8.5	-36.0	6.0	0.0	13.0	0.0	0.0
9.5	-29.5	2.0	0.0	17.0	0.0	0.0
10.5	-22.3	2.0	0.0	0.0	0.0	0.0
11.5	-14.2	3.0	1.0	0.0	0.0	0.0
12.5	-5.3	0.0	0.0	0.0	0.0	0.0
13.5	4.3	10.0	0.0	9.0	0.0	0.0
14.5	14.8	0.0	0.0	14.0	0.0	0.0
15.5	26.4	0.0	0.0	0.0	0.0	0.0
16.5	39.4	0.0	0.0	0.0	1.0	3.0
17.5	53.7	0.0	0.0	13.0	2.0	0.0
18.5	69.4	0.0	0.0	0.0	1.0	0.0
19.5	86.2	0.0	10.0	0.0	0.0	0.0
20.5	104.4	0.0	3.0	0.0	0.0	0.0
21.5	123.7	36.0	9.0	0.0	0.0	0.0
22.5	144.3	0.0	24.0	0.0	0.0	0.0
23.5	166.0	0.0	0.0	0.0	0.0	0.0
24.5	188.9	0.0	0.0	3.0	0.0	0.0
25.5	212.9	0.0	0.0	0.0	0.0	0.0
26.5	238.0	1.0	0.0	0.0	0.0	0.0
27.5	264.2	8.0	3.0	4.0	0.0	0.0
28.5	291.5	0.0	0.0	0.0	0.0	0.0
29.5	319.8	0.0	0.0	0.0	0.0	0.0
30.5	349.1	0.0	0.0	0.0	0.0	0.0
31.5	379.4	0.0	0.0	6.0	0.0	0.0
33.5	442.9	0.0	0.0	1.0	4.0	0.0
34.5	476.0	0.0	0.0	0.0	0.0	0.0
35.5	510.1	31.0	0.0	0.0	0.0	0.0
36.5	545.0	1.0	0.0	4.0	0.0	0.0
37.5	580.8	0.0	10.0	0.0	0.0	0.0
38.5	617.4	9.0	21.0	0.0	0.0	0.0
39.5	654.8	0.0	3.0	0.0	0.0	0.0
40.5	693.0	0.0	0.0	11.0	0.0	0.0
41.5	731.9	0.0	0.0	0.0	0.0	0.0
42.5	771.6	0.0	15.0	0.0	0.0	0.0
43.5	812.0	0.0	4.0	0.0	0.0	0.0

Average Depth (cm)	Cal yrs BP	*Sphagnum*	*Equisetum*	*Myriophyllum*	*Potamogeton*	*Typha*
44.5	853.1	5.0	0.0	0.0	0.0	0.0
48.5	1024.0	3.0	4.0	1.0	3.0	0.0
49.5	1068.2	0.0	0.0	1.0	4.0	0.0
56.5	1391.8	0.0	0.0	1.0	0.0	0.0
60.5	1585.8	0.0	0.0	0.0	0.0	0.0
64.5	1784.5	0.0	2.0	1.0	0.0	0.0
65.5	1834.8	5.0	0.0	0.0	0.0	0.0
68.5	1986.5	3.0	3.0	0.0	0.0	0.0
70.5	2088.3	1.0	11.0	0.0	0.0	0.0
72.5	2190.4	0.0	0.0	0.0	1.0	0.0
74.5	2292.5	3.0	5.0	0.0	0.0	0.0
76.5	2394.5	0.0	20.0	0.0	0.0	0.0
77.5	2445.4	0.0	6.0	0.0	0.0	0.0
78.5	2496.2	0.0	14.0	0.0	0.0	0.0
79.5	2546.9	0.0	0.0	0.0	0.0	0.0
80.5	2597.5	0.0	0.0	2.0	1.0	1.0
81.5	2647.8	0.0	0.0	2.0	0.0	0.0
84.5	2797.8	0.0	7.0	0.0	0.0	0.0
88.5	2994.0	0.0	0.0	1.0	0.0	0.0
92.5	3184.5	0.0	0.0	0.0	0.0	0.0
97.5	3416.6	3.0	0.0	0.0	1.0	0.0
100.5	3554.7	5.0	0.0	0.0	0.0	0.0
104.5	3737.7	0.0	0.0	2.0	2.0	0.0
108.5	3919.4	3.0	9.0	0.0	0.0	0.0
112.5	4099.9	1.0	0.0	1.0	2.0	0.0
113.5	4144.8	1.0	0.0	0.0	0.0	0.0
116.5	4279.3	3.0	0.0	0.0	0.0	0.0
120.5	4457.8	4.0	0.0	0.0	0.0	0.0
122.5	4546.8	0.0	1.0	0.0	0.0	0.0
124.5	4635.5	0.0	0.0	0.0	0.0	0.0
125.5	4679.7	0.0	0.0	0.0	0.0	0.0
126.5	4724.0	0.0	0.0	0.0	5.0	0.0
127.5	4768.2	4.0	3.0	0.0	0.0	0.0
128.5	4812.3	7.0	0.0	0.0	3.0	0.0
129.5	4856.4	0.0	0.0	0.0	2.0	0.0
130.5	4900.5	15.0	1.0	0.0	0.0	0.0
132.5	4988.5	13.0	4.0	0.0	0.0	0.0
136.5	5164.2	0.0	0.0	1.0	1.0	0.0
140.5	5339.3	17.0	3.0	0.0	0.0	0.0
144.5	5514.2	1.0	0.0	0.0	1.0	0.0
145.5	5557.8	1.0	1.0	0.0	0.0	0.0
148.5	5688.7	8.0	0.0	0.0	0.0	0.0
152.5	5863.1	0.0	0.0	0.0	0.0	0.0

Average Depth (cm)	Cal yrs BP	*Sphagnum*	*Equisetum*	*Myriophyllum*	*Potamogeton*	*Typha*
156.5	6037.4	0.0	2.0	0.0	0.0	0.0
160.5	6211.8	0.0	0.0	0.0	1.0	1.0
161.5	6255.4	2.0	0.0	3.0	2.0	0.0
164.5	6386.4	0.0	0.0	0.0	0.0	0.0
168.5	6561.1	0.0	0.0	4.0	1.0	0.0
170.5	6648.6	3.0	8.0	0.0	0.0	0.0
172.5	6736.2	1.0	3.0	0.0	0.0	0.0
174.5	6824.0	0.0	0.0	0.0	0.0	0.0
176.5	6911.8	0.0	0.0	1.0	1.0	0.0
177.5	6955.8	1.0	0.0	0.0	0.0	0.0
178.5	6999.8	3.0	4.0	0.0	0.0	0.0
179.5	7043.8	3.0	0.0	0.0	0.0	3.0
180.5	7087.9	0.0	1.0	0.0	0.0	0.0
181.5	7132.0	0.0	0.0	0.0	0.0	0.0
184.5	7264.7	0.0	0.0	0.0	0.0	0.0
188.5	7442.2	13.0	0.0	0.0	0.0	0.0
192.5	7620.5	2.0	1.0	0.0	2.0	0.0
193.5	7665.2	0.0	0.0	0.0	1.0	0.0
200.5	7980.2	1.0	1.0	0.0	0.0	0.0
204.5	8161.7	9.0	0.0	0.0	0.0	0.0
208.5	8344.4	0.0	0.0	0.0	1.0	2.0
209.5	8390.3	0.0	0.0	0.0	1.0	0.0
212.5	8528.5	7.0	0.0	0.0	0.0	0.0
216.5	8714.1	2.0	0.0	9.0	2.0	0.0
220.5	8901.2	0.0	6.0	0.0	0.0	0.0
224.5	9090.0	6.0	0.0	2.0	0.0	1.0
225.5	9137.5	0.0	0.0	0.0	1.0	1.0
228.5	9280.6	2.0	0.0	0.0	0.0	0.0
232.5	9472.9	0.0	0.0	0.0	2.0	0.0
236.5	9667.3	0.0	0.0	0.0	0.0	0.0
240.5	9863.7	0.0	1.0	0.0	1.0	0.0
241.5	9913.1	0.0	0.0	0.0	0.0	0.0
242.5	9962.7	0.0	0.0	15.0	0.0	0.0
243.5	10012.4	6.0	5.0	0.0	0.0	0.0
244.5	10062.3	8.0	3.0	0.0	0.0	0.0
245.5	10112.3	0.0	21.0	0.0	0.0	0.0
246.5	10162.4	0.0	1.0	0.0	0.0	0.0
247.5	10212.7	14.0	3.0	0.0	1.0	3.0
248.5	10263.1	0.0	0.0	0.0	0.0	0.0
249.5	10313.7	0.0	33.0	0.0	0.0	0.0

Average Depth (cm)	Cal yrs BP	*Pediastrum*	Unknown/Unidentifiable	Spike	Algae	Aquatics	Spores
0.5		0.0	2.0	0.0	0.0	125.0	2.0
1.5	-59.0	0.0	2.0	908.0	0.0	65.0	8.0
2.5	-58.1	11.0	3.0	486.0	11.0	28.0	12.0
3.5	-56.4	0.0	5.0	471.0	0.0	8.0	24.0
4.5	-53.9	6.0	6.0	325.0	6.0	40.0	7.0
5.5	-50.6	4.0	1.0	496.0	4.0	28.0	14.0
6.5	-46.6	5.0	3.0	731.0	5.0	32.0	16.0
7.5	-41.7	2.0	4.0	1134.0	2.0	42.0	17.0
8.5	-36.0	0.0	2.0	882.0	0.0	19.0	3.0
9.5	-29.5	5.0	2.0	449.0	5.0	19.0	11.0
10.5	-22.3	7.0	1.0	367.0	7.0	2.0	3.0
11.5	-14.2	6.0	6.0	473.0	6.0	4.0	6.0
12.5	-5.3	1.0	3.0	208.0	1.0	0.0	36.0
13.5	4.3	0.0	6.0	677.0	0.0	19.0	35.0
14.5	14.8	36.0	11.0	897.0	36.0	14.0	3.0
15.5	26.4	0.0	3.0	345.0	0.0	0.0	3.0
16.5	39.4	0.0	2.0	0.0	0.0	4.0	6.0
17.5	53.7	0.0	5.0	438.0	0.0	15.0	10.0
18.5	69.4	0.0	4.0	367.0	0.0	1.0	6.0
19.5	86.2	4.0	4.0	400.0	4.0	10.0	14.0
20.5	104.4	2.0	3.0	768.0	2.0	3.0	11.0
21.5	123.7	18.0	7.0	657.0	18.0	45.0	10.0
22.5	144.3	0.0	3.0	989.0	0.0	24.0	0.0
23.5	166.0	5.0	7.0	964.0	5.0	0.0	0.0
24.5	188.9	1.0	3.0	984.0	1.0	3.0	0.0
25.5	212.9	0.0	4.0	1283.0	0.0	0.0	4.0
26.5	238.0	15.0	4.0	661.0	15.0	1.0	6.0
27.5	264.2	29.0	3.0	463.0	29.0	15.0	13.0
28.5	291.5	1.0	6.0	873.0	1.0	0.0	31.0
29.5	319.8	16.0	5.0	413.0	16.0	0.0	6.0
30.5	349.1	0.0	4.0	1869.0	0.0	0.0	10.0
31.5	379.4	0.0	4.0	1146.0	0.0	6.0	6.0
33.5	442.9	0.0	1.0	1005.0	0.0	5.0	4.0
34.5	476.0	1.0	5.0	1045.0	1.0	0.0	10.0
35.5	510.1	8.0	4.0	339.0	8.0	31.0	17.0
36.5	545.0	1.0	8.0	604.0	1.0	5.0	0.0
37.5	580.8	11.0	6.0	347.0	11.0	10.0	36.0
38.5	617.4	0.0	6.0	853.0	0.0	30.0	38.0
39.5	654.8	0.0	6.0	396.0	0.0	3.0	15.0
40.5	693.0	0.0	2.0	998.0	0.0	11.0	7.0
41.5	731.9	10.0	5.0	767.0	10.0	0.0	9.0
42.5	771.6	0.0	7.0	804.0	0.0	15.0	10.0
43.5	812.0	11.0	9.0	485.0	11.0	4.0	38.0

Average Depth (cm)	Cal yrs BP	*Pediastrum*	Unknown/Unidentifiable	Spike	Algae	Aquatics	Spores
44.5	853.1	19.0	5.0	1050.0	19.0	5.0	12.0
48.5	1024.0	0.0	6.0	0.0	0.0	11.0	9.0
49.5	1068.2	2.0	2.0	1339.0	2.0	5.0	4.0
56.5	1391.8	0.0	2.0	1472.0	0.0	1.0	0.0
60.5	1585.8	2.0	6.0	328.0	2.0	0.0	25.0
64.5	1784.5	0.0	5.0	0.0	0.0	3.0	4.0
65.5	1834.8	0.0	4.0	880.0	0.0	5.0	0.0
68.5	1986.5	0.0	3.0	440.0	0.0	6.0	9.0
70.5	2088.3	29.0	7.0	307.0	29.0	12.0	20.0
72.5	2190.4	0.0	0.0	714.0	0.0	1.0	4.0
74.5	2292.5	0.0	3.0	621.0	0.0	8.0	14.0
76.5	2394.5	0.0	6.0	733.0	0.0	20.0	28.0
77.5	2445.4	0.0	3.0	87.0	0.0	6.0	39.0
78.5	2496.2	23.0	4.0	398.0	23.0	14.0	2.0
79.5	2546.9	0.0	7.0	297.0	0.0	0.0	12.0
80.5	2597.5	0.0	7.0	0.0	0.0	4.0	5.0
81.5	2647.8	0.0	0.0	1208.0	0.0	2.0	2.0
84.5	2797.8	0.0	2.0	1158.0	0.0	7.0	3.0
88.5	2994.0	0.0	0.0	434.0	0.0	1.0	3.0
92.5	3184.5	9.0	4.0	506.0	9.0	0.0	12.0
97.5	3416.6	0.0	4.0	1276.0	0.0	4.0	6.0
100.5	3554.7	16.0	13.0	865.0	16.0	5.0	24.0
104.5	3737.7	0.0	4.0	433.0	0.0	4.0	9.0
108.5	3919.4	18.0	3.0	453.0	18.0	12.0	14.0
112.5	4099.9	0.0	7.0	0.0	0.0	4.0	8.0
113.5	4144.8	2.0	2.0	1200.0	2.0	1.0	0.0
116.5	4279.3	0.0	4.0	333.0	0.0	3.0	8.0
120.5	4457.8	0.0	1.0	670.0	0.0	4.0	3.0
122.5	4546.8	11.0	5.0	373.0	11.0	1.0	24.0
124.5	4635.5	6.0	3.0	351.0	6.0	0.0	10.0
125.5	4679.7	2.0	2.0	392.0	2.0	0.0	9.0
126.5	4724.0	1.0	3.0	331.0	1.0	5.0	16.0
127.5	4768.2	5.0	5.0	600.0	5.0	7.0	2.0
128.5	4812.3	0.0	6.0	0.0	0.0	10.0	10.0
129.5	4856.4	0.0	2.0	680.0	0.0	2.0	1.0
130.5	4900.5	9.0	1.0	398.0	9.0	16.0	3.0
132.5	4988.5	11.0	4.0	1402.0	11.0	17.0	25.0
136.5	5164.2	0.0	0.0	942.0	0.0	2.0	0.0
140.5	5339.3	15.0	4.0	400.0	15.0	20.0	5.0
144.5	5514.2	0.0	0.0	0.0	0.0	2.0	1.0
145.5	5557.8	0.0	0.0	964.0	0.0	2.0	0.0
148.5	5688.7	3.0	3.0	1143.0	3.0	8.0	8.0
152.5	5863.1	0.0	0.0	714.0	0.0	0.0	0.0

Average Depth (cm)	Cal yrs BP	*Pediastrum*	Unknown/Unidentifiable	Spike	Algae	Aquatics	Spores
156.5	6037.4	12.0	3.0	883.0	12.0	2.0	5.0
160.5	6211.8	0.0	4.0	0.0	0.0	2.0	5.0
161.5	6255.4	0.0	5.0	3054.0	0.0	7.0	8.0
164.5	6386.4	9.0	3.0	695.0	9.0	0.0	6.0
168.5	6561.1	0.0	2.0	708.0	0.0	5.0	4.0
170.5	6648.6	13.0	3.0	332.0	13.0	11.0	37.0
172.5	6736.2	21.0	5.0	573.0	21.0	4.0	19.0
174.5	6824.0	3.0	3.0	660.0	3.0	0.0	10.0
176.5	6911.8	0.0	1.0	0.0	0.0	2.0	2.0
177.5	6955.8	0.0	0.0	1020.0	0.0	1.0	0.0
178.5	6999.8	2.0	3.0	297.0	2.0	7.0	7.0
179.5	7043.8	20.0	4.0	966.0	20.0	6.0	5.0
180.5	7087.9	3.0	5.0	1247.0	3.0	1.0	12.0
181.5	7132.0	7.0	11.0	187.0	7.0	0.0	25.0
184.5	7264.7	0.0	2.0	824.0	0.0	0.0	8.0
188.5	7442.2	5.0	3.0	642.0	5.0	13.0	20.0
192.5	7620.5	0.0	1.0	0.0	0.0	5.0	5.0
193.5	7665.2	0.0	3.0	405.0	0.0	1.0	0.0
200.5	7980.2	0.0	1.0	402.0	0.0	2.0	2.0
204.5	8161.7	22.0	8.0	755.0	22.0	9.0	25.0
208.5	8344.4	0.0	6.0	0.0	0.0	3.0	1.0
209.5	8390.3	0.0	3.0	528.0	0.0	1.0	11.0
212.5	8528.5	0.0	4.0	422.0	0.0	7.0	5.0
216.5	8714.1	0.0	1.0	884.0	0.0	13.0	12.0
220.5	8901.2	3.0	6.0	268.0	3.0	6.0	14.0
224.5	9090.0	0.0	1.0	0.0	0.0	9.0	13.0
225.5	9137.5	0.0	1.0	712.0	0.0	2.0	4.0
228.5	9280.6	1.0	3.0	997.0	1.0	2.0	7.0
232.5	9472.9	0.0	1.0	605.0	0.0	2.0	3.0
236.5	9667.3	9.0	4.0	864.0	9.0	0.0	19.0
240.5	9863.7	0.0	4.0	0.0	0.0	2.0	5.0
241.5	9913.1	0.0	0.0	1500.0	0.0	0.0	11.0
242.5	9962.7	13.0	5.0	793.0	13.0	15.0	15.0
243.5	10012.4	19.0	3.0	459.0	19.0	11.0	6.0
244.5	10062.3	1.0	6.0	1582.0	1.0	11.0	18.0
245.5	10112.3	12.0	7.0	437.0	12.0	21.0	19.0
246.5	10162.4	8.0	10.0	301.0	8.0	1.0	52.0
247.5	10212.7	15.0	2.0	351.0	15.0	21.0	10.0
248.5	10263.1	0.0	2.0	1078.0	0.0	0.0	4.0
249.5	10313.7	49.0	9.0	1212.0	49.0	33.0	32.0

Average Depth (cm)	Cal yrs BP	NAP	AP	Total no Aquatics or Algae	Total Aquatics no Algae	Total Aquatics and Algae
0.5		77.0	380.0	459.0	584.0	584.0
1.5	-59.0	60.0	451.0	519.0	584.0	584.0
2.5	-58.1	39.0	359.0	410.0	438.0	449.0
3.5	-56.4	68.0	371.5	463.5	471.5	471.5
4.5	-53.9	74.0	651.0	732.0	772.0	778.0
5.5	-50.6	46.0	429.0	489.0	517.0	521.0
6.5	-46.6	48.0	646.5	710.5	742.5	747.5
7.5	-41.7	46.0	634.0	697.0	739.0	741.0
8.5	-36.0	29.0	871.5	903.5	922.5	922.5
9.5	-29.5	27.0	387.5	425.5	444.5	449.5
10.5	-22.3	19.0	400.0	422.0	424.0	431.0
11.5	-14.2	57.0	563.0	626.0	630.0	636.0
12.5	-5.3	33.0	513.0	582.0	582.0	583.0
13.5	4.3	36.0	516.0	587.0	606.0	606.0
14.5	14.8	74.0	661.5	738.5	752.5	788.5
15.5	26.4	40.0	539.5	582.5	582.5	582.5
16.5	39.4	43.0	522.5	571.5	575.5	575.5
17.5	53.7	34.0	612.5	656.5	671.5	671.5
18.5	69.4	68.0	500.0	574.0	575.0	575.0
19.5	86.2	35.0	598.5	647.5	657.5	661.5
20.5	104.4	36.0	588.0	635.0	638.0	640.0
21.5	123.7	83.0	454.0	547.0	592.0	610.0
22.5	144.3	98.0	372.5	470.5	494.5	494.5
23.5	166.0	56.0	631.0	687.0	687.0	692.0
24.5	188.9	15.0	649.0	664.0	667.0	668.0
25.5	212.9	34.0	579.5	617.5	617.5	617.5
26.5	238.0	23.0	518.0	547.0	548.0	563.0
27.5	264.2	78.0	483.0	574.0	589.0	618.0
28.5	291.5	79.0	422.5	532.5	532.5	533.5
29.5	319.8	46.0	458.5	510.5	510.5	526.5
30.5	349.1	46.0	685.0	741.0	741.0	741.0
31.5	379.4	39.0	557.5	602.5	608.5	608.5
33.5	442.9	37.0	712.5	753.5	758.5	758.5
34.5	476.0	54.0	541.5	605.5	605.5	606.5
35.5	510.1	55.0	459.5	531.5	562.5	570.5
36.5	545.0	21.0	430.0	451.0	456.0	457.0
37.5	580.8	96.0	396.0	528.0	538.0	549.0
38.5	617.4	114.0	444.0	596.0	626.0	626.0
39.5	654.8	33.0	402.0	450.0	453.0	453.0
40.5	693.0	58.0	481.0	546.0	557.0	557.0
41.5	731.9	63.0	428.0	500.0	500.0	510.0
42.5	771.6	45.0	488.5	543.5	558.5	558.5
43.5	812.0	95.0	330.0	463.0	467.0	478.0

Average Depth (cm)	Cal yrs BP	NAP	AP	Total no Aquatics or Algae	Total Aquatics no Algae	Total Aquatics and Algae
44.5	853.1	53.0	454.0	519.0	524.0	543.0
48.5	1024.0	72.0	489.5	570.5	581.5	581.5
49.5	1068.2	18.0	815.5	837.5	842.5	844.5
56.5	1391.8	13.0	239.0	252.0	253.0	253.0
60.5	1585.8	41.0	409.0	475.0	475.0	477.0
64.5	1784.5	24.0	696.5	724.5	727.5	727.5
65.5	1834.8	45.0	678.5	723.5	728.5	728.5
68.5	1986.5	69.0	591.5	669.5	675.5	675.5
70.5	2088.3	84.0	542.5	646.5	658.5	687.5
72.5	2190.4	17.0	520.0	541.0	542.0	542.0
74.5	2292.5	76.0	615.5	705.5	713.5	713.5
76.5	2394.5	58.0	519.5	605.5	625.5	625.5
77.5	2445.4	92.0	437.5	568.5	574.5	574.5
78.5	2496.2	99.0	424.5	525.5	539.5	562.5
79.5	2546.9	62.0	467.5	541.5	541.5	541.5
80.5	2597.5	19.0	765.0	789.0	793.0	793.0
81.5	2647.8	27.0	828.0	857.0	859.0	859.0
84.5	2797.8	68.0	593.0	664.0	671.0	671.0
88.5	2994.0	20.0	506.0	529.0	530.0	530.0
92.5	3184.5	63.0	405.0	480.0	480.0	489.0
97.5	3416.6	51.0	758.5	815.5	819.5	819.5
100.5	3554.7	62.0	508.5	594.5	599.5	615.5
104.5	3737.7	20.0	521.0	550.0	554.0	554.0
108.5	3919.4	52.0	454.0	520.0	532.0	550.0
112.5	4099.9	40.0	538.0	586.0	590.0	590.0
113.5	4144.8	19.0	686.0	705.0	706.0	708.0
116.5	4279.3	33.0	603.5	644.5	647.5	647.5
120.5	4457.8	21.0	706.0	730.0	734.0	734.0
122.5	4546.8	39.0	469.5	532.5	533.5	544.5
124.5	4635.5	42.0	507.5	559.5	559.5	565.5
125.5	4679.7	11.0	609.0	629.0	629.0	631.0
126.5	4724.0	96.0	570.5	682.5	687.5	688.5
127.5	4768.2	49.0	470.5	521.5	528.5	533.5
128.5	4812.3	50.0	621.5	681.5	691.5	691.5
129.5	4856.4	13.0	556.5	570.5	572.5	572.5
130.5	4900.5	59.0	606.0	668.0	684.0	693.0
132.5	4988.5	24.0	492.5	541.5	558.5	569.5
136.5	5164.2	25.0	634.0	659.0	661.0	661.0
140.5	5339.3	58.0	551.5	614.5	634.5	649.5
144.5	5514.2	13.0	642.5	656.5	658.5	658.5
145.5	5557.8	22.0	594.0	616.0	618.0	618.0
148.5	5688.7	42.0	529.0	579.0	587.0	590.0
152.5	5863.1	15.0	554.0	569.0	569.0	569.0

Average Depth (cm)	Cal yrs BP	NAP	AP	Total no Aquatics or Algae	Total Aquatics no Algae	Total Aquatics and Algae
156.5	6037.4	44.0	455.0	504.0	506.0	518.0
160.5	6211.8	17.0	591.5	613.5	615.5	615.5
161.5	6255.4	56.0	903.0	967.0	974.0	974.0
164.5	6386.4	31.0	463.0	500.0	500.0	509.0
168.5	6561.1	19.0	673.0	696.0	701.0	701.0
170.5	6648.6	48.0	470.0	555.0	566.0	579.0
172.5	6736.2	54.0	464.5	537.5	541.5	562.5
174.5	6824.0	59.0	495.5	564.5	564.5	567.5
176.5	6911.8	15.0	586.0	603.0	605.0	605.0
177.5	6955.8	29.0	511.0	540.0	541.0	541.0
178.5	6999.8	54.0	513.5	574.5	581.5	583.5
179.5	7043.8	36.0	594.0	635.0	641.0	661.0
180.5	7087.9	59.0	662.5	733.5	734.5	737.5
181.5	7132.0	104.0	336.5	465.5	465.5	472.5
184.5	7264.7	24.0	601.0	633.0	633.0	633.0
188.5	7442.2	44.0	640.5	704.5	717.5	722.5
192.5	7620.5	68.0	538.5	611.5	616.5	616.5
193.5	7665.2	10.0	613.5	623.5	624.5	624.5
200.5	7980.2	18.0	533.0	553.0	555.0	555.0
204.5	8161.7	67.0	526.5	618.5	627.5	649.5
208.5	8344.4	32.0	568.0	601.0	604.0	604.0
209.5	8390.3	17.0	560.0	588.0	589.0	589.0
212.5	8528.5	23.0	554.5	582.5	589.5	589.5
216.5	8714.1	61.0	551.0	624.0	637.0	637.0
220.5	8901.2	61.0	507.5	582.5	588.5	591.5
224.5	9090.0	61.0	529.0	603.0	612.0	612.0
225.5	9137.5	18.0	517.5	539.5	541.5	541.5
228.5	9280.6	30.0	464.5	501.5	503.5	504.5
232.5	9472.9	14.0	902.0	919.0	921.0	921.0
236.5	9667.3	97.0	531.5	647.5	647.5	656.5
240.5	9863.7	45.0	759.5	809.5	811.5	811.5
241.5	9913.1	56.0	469.0	536.0	536.0	536.0
242.5	9962.7	132.0	503.5	650.5	665.5	678.5
243.5	10012.4	56.0	414.5	476.5	487.5	506.5
244.5	10062.3	41.0	540.0	599.0	610.0	611.0
245.5	10112.3	74.0	505.5	598.5	619.5	631.5
246.5	10162.4	136.0	346.5	534.5	535.5	543.5
247.5	10212.7	77.0	406.0	493.0	514.0	529.0
248.5	10263.1	54.0	487.0	545.0	545.0	545.0
249.5	10313.7	81.0	476.0	589.0	622.0	671.0

Appendix B. Pollen taxa retained for paleoclimate reconstruction (Modern Analogue Technique; MAT) and Principal Components Analysis (PCA)

A. MAT – Pollen types retained included: *Picea* (sum of *Picea glauca*, *Picea mariana*, *Picea* undiff), *Pinus* (*Pinus* diploxylon, *Pinus* haploxylon, *Pinus* undiff) *Populus*, Cupressaceae (*Juniperus*) *Alnus* (Alnus *crispa* and *Alnus rugosa*), *Betula*, *Shepherdia*, *Salix*, *Ambrosia*, *Artemisia*, Asteraceae (sum of Asteraceae – Tubuliflorae, Asteraceae – Liguliflorae), Caryophyllaceae, Chenopodiaceae, *Cornus* (*Cornus*, *Cornus canadensis*), Brassicaceae (Cruciferae), Cyperaceae, *Dryas*, Ericaceae, Onagraceae (*Epilobium)*, Rubiaceae (*Galium)*, Poaceae, *Polygonum viviparum*, *Potentilla*, *Ranunculus*, Rosaceae, Saxifragaceae, *Saxifraga oppositifolia*, *Thalictrum*, Apiaceae (Umbelliferae), Polypodiaceae, *Pteridium*, *Lycopodium*, *Sphagnum.*

B. PCA – Pollen types retained for this analysis included: *Picea glauca*, *Picea mariana*, *Pinus* diploxylon, *Populus*, *Juniperus*, *Alnus crispa*, *Betula*, *Shepherdia*, *Salix*, Cyperaceae, *Epilobium*, Poaceae, Polypodiaceae, *Sphagnum*, Other AP (sum of *Picea* undiff, *Pinus* haploxylon, *Pinus* undiff, *Alnus rugosa*, Ericaceae), Other NAP (*Ambrosia*, *Artemisia*, Asteraceae – Tubuliflorae, Asteraceae – Liguliflorae, Caryophyllaceae, Chenopodiaceae, *Cornus*, *Cornus canadensis*, Cruciferae, *Dryas*, *Galium*, *Polygonum viviparum*, *Potentilla*, *Ranunculus*, Rosaceae, Saxifragaceae, *Saxifraga oppositifolia*, *Thalictrum*, *Umbelliferae*), Other Spores (*Pteridium*, *Lycopodium*), Other Aquatics (*Equisetum*, *Myriophyllum*, *Potamogeton*, *Typha*).