Post-glacial pollen and charcoal analysis of a 10,500-year lake sediment record from Lower Whitshed Lake near Cordova, Alaska

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Introduction

Charcoal records can be used to interpret climate change events of the past, as well as an indicator of vegetation changes as a result of fire events in a local environment (Flannigan et al. 2000). In addition to charcoal, fossil pollen is useful not only in determining rates of plant migration, but also to track climate change (Pitelka 1997). The studies of historical plant migration and vegetation change may also be used to predict how plants will respond to present day climate change as well as to changes in the local fire regime. This study uses proxy data such as charcoal particles, fossil pollen, and sediment characteristics made available from a sediment core taken from southeastern Alaska to understand the climatic, vegetation, and fire changes over a 10,500 year period.

As the climate changes, plant species migrate towards regions that are more hospitable (Davis & Shaw 2001); this migration can be determined with corresponding pollen records on a continental scale. This information can be used to predict migration and colonization rates of native species in response to habitat loss and climate change (Higgins and Richardson 1999). Whether a species is a new arrival in a region or reestablishing after fire, understanding the abiotic factors such as climate or fire that influence vegetation is important.

Pollen analysis is commonly used for vegetation reconstructions as well as making inferences about climatic variation over a given time period (Huntley 1996). For example, Jones et al. (2009) analyzed pollen, plant macrofossils, spores and carbon-14 dating to provide a vegetation history and climate record of the Kenai Peninsula region. They found that a period of *Betula* expansion and herb tundra contraction was associated with the Younger Dryas stadial, an event in which global climate cooled rapidly. The study suggests that vegetation types such as *Artemisia* (wormwood) are indicative of cold and dry conditions, while an influx of wet meadow
species and disappearance of aquatic species indicates warm and drying conditions. Studies similar to these are able to use pollen data in a similar way to accurately reconstruct corresponding climate change. However, pollen studies are not the only proxy indicator of climate change, sediment characteristics are also used to interpret historical climate change.

When temperatures increase, water locked up in glaciers and sea ice melts, contributing to sea level rise (Kapp et al. 1990). These heightened water levels in Earth’s oceans may consume portions of the land surface, even lead to flooding of basins further inland, an occurrence that is evident to have occurred at the study site through the change in sediment type. The warming of sea surfaces and the response of melting ice also leads to increases in precipitation (Houghton 2009). In areas such as the study site, rainfall is amplified due to its coastal proximity. This increase in rainfall could have resulted in major changes in vegetation as well as have made it more difficult for fire events to occur over extended wet periods. The apparent changes in sediment type as a result of rapid sedimentation inform that the site experience these changes and also allows for a better understanding of climatic variation.

Charcoal analysis has been used successfully to determine the history of fire events over thousands of years. In using charcoal analysis programs, “peaks” of fire can be determined by analyzing the abundance, area, and volume of charcoal particles present in samples (Ali et al. 2009). However, few studies have described the history of fire in southern Alaska (Berg & Anderson 2006). Many forest types in this area do not burn frequently; however, black spruce (Picea mariana) forests burn at a frequency of 79 years (Berg & Anderson 2006). My near-coastal study site in southeastern Alaska is currently surrounded by a spruce/hemlock forest containing black spruce. Given the fire frequency of this forest type, it is likely that fires have been part of the natural disturbance regime beginning with the arrival of black spruce until the
present. With fire also clearing the area for more fire resistant vegetation to flourish, or even new vegetation altogether, it should be linkable to rapid changes in vegetation type over short periods of time.

The objective of this study is to examine the pollen and charcoal from a lake sediment core that was extracted from Lower Whitshed Lake near Cordova, Alaska. I will use these data to describe the region’s vegetation history; to determine previous regional climates by interpreting proxy data; and to describe the region’s fire history. Overall, I aim to examine the relationships between climate change and vegetation, as well as fire events and vegetation in this region of Alaska. A portion of the study will focus specifically on the migrations and expansion of western hemlock (*Tsuga heterophylla*) and mountain hemlock (*T. mertensiana*), two tree species that have a limited expansion range from coastal northern California to the southern coast of Alaska. This particular study site is immediately near the approximate habitat limit of both species, and also lies less than 1 km from the coast. Its coastal proximity makes it an interesting site to view fire events as they are not common in sites with high levels of precipitation. However, these fire events, though uncommon, may also provide insight to some of the vegetation changes that may not correspond with other literature. The data provided from the vegetation and fire reconstructions of this site will provide in-depth historical information on fire regimes in a region where little knowledge currently exists.

In this study, I will ask the following questions:

- Does proximity to the coast alter the expected arrival time of *Tsuga mertensiana* and *Tsuga heterophylla* because they are coastal trees?
- How does vegetation respond to fire events in the historical record?
- Do fire events have low frequency, consistent with other coastal sites?
Will “peaks” in charcoal events increase after the arrival of black spruce to the study site?
Will charcoal “peaks” be consistent with rapid vegetation changes, thus suggesting that fire events drove those changes?

Materials and Methods

STUDY SITE

Whitshed Lake is composed of two freshwater basins located near Cordova, Alaska. The smaller of the two is the study site for this research. Lower Whitshed Lake is located approximately 1 kilometer from the coast of the Orca Inlet and 16.4 kilometers from the populated city of Cordova. It has received an average of 2388.1 centimeters of rain over the past 40 years at its coastal regions and has had an average temperature of 4.1 degrees °C over the past century (WorldClimate.com).

A sediment core was previously taken by members of the Anderson and Kaufman labs from the smaller of the two Whitshed basins in 2010. A universal percussion corer was used to extract 261 centimeters of sediment from the deepest part of the lake. The sediment was then wrapped in plastic, aluminum foil, and stored in an ice chest filled with dry ice. In the laboratory, the sediment core was vertically cut in half and stored in coolers until sampling. Carbon dates were previously interpolated from dated samples in the core taken at 250 cm, 135 cm, and 55 cm: these dates were 10,572 cal BP (calendar years before present), 1439 AD, and 1819 AD, respectively (Anderson & Kaufman, unpublished data).
POLLEN ANALYSIS

Pollen analysis took place between in winter of 2010 and was concluded in the summer of 2011. One cubic centimeter (cc) samples were taken in 2.5 cm intervals beginning at the top of the organic portion of the sediment core and processed for fossil pollen using the modified Faegri and Iversen (1989) technique (Fig. 1). In brief, samples were added to a KOH suspension followed by dilution of HCl, HF, and acetolysis solution. Two Lycopodium spore tablets were added with known concentrations as tracers for pollen concentration. Identifications were made using the Northern Arizona Laboratory of Paleoecology’s (LoP) modern pollen reference collection as well as Kapp (1969).

Pollen grains from each processed sample were viewed at 400x under a light microscope and counted until a minimum of 300 grains was reached. These grains were identified to family or genus if possible; when species were accurately identified they were also used. Aquatic and wetland pollen and spores were excluded from the count because terrestrial vegetation is where the main focus lies (Anderson et al. 2010). Pollen assemblages determined from these methods will be compared to that of cores from regions more inland of Southeastern Alaska to understand both the comparable timing of vegetation changes among sites in the area as well as the climatic implications.

Finally, these pollen assemblages will be used to compare vegetation changes to fire events determined by charcoal analysis (explained below). In the event that the resolution is not clear when comparing vegetation changes to fire events, more pollen samples will be processed and analyzed from the core.
CHARCOAL ANALYSIS

Charcoal analysis was begun in fall 2011 in order to determine the fire frequency of the Lower Whitshed Lake region. Two cc samples were taken systematically from the sediment core in 0.5 cm increments for charcoal analysis. Each individual sample was stored in a small plastic applesauce cup with sodium hexametaphosphate to break up the sediment for sieving. After two days of sitting in this solution, the samples were sieved into two different size classes: 250µ and 125µ. Each size class was stored separately in tap water until analysis.

For analysis both size classes from each sample will be poured into petri dishes and viewed under a stereoscopic microscope at 25-50 X magnification. Charcoal particles on the entire dish will be counted and documented for every depth in the core. Any other non-charcoal plant material will also be documented in the event that it is a high-resolution proxy for changes in the lake. Charcoal will be converted to concentration, then influx into the basin will be calculated, then “peaks” will be determined using CharAnalysis v. 1.1. These “peaks” represent a high likelihood of a localized fire event and will thus be compared with the vegetation reconstruction already performed to examine relationships between fire events and vegetation composition (Jimenez-Moreno et al. 2011).

Preliminary and Anticipated Results

In my analysis of the sediment core, I have first established that pollen cannot be detected in the top 100 cm. There was an abrupt change in sediment type from gyttja (an organic lake mud) to inorganic silt at 100 cm that did not have a statistically significant amount of pollen (Fig. 1). This is likely a result of rapid deposition of sediment that drastically reduced the
concentration of pollen by increasing the amount of sediment influx. This rapid deposition was caused by inundation of silt into the basin. For this reason, all following analyses and discussion will involve the sediment core below 100 cm.

Coastal proximity did not affect the arrival time of *Tsuga heterophylla* and *T. mertensiana* which means that increased precipitation in this area did not delay or speed up the rates of colonization. As expected, *T. mertensiana* arrived first; the only unexpected result was the higher abundance of *T. heterophylla* compared to *T. mertensiana* after establishment of both species (Fig. 2). This dominance of *T. heterophylla* is likely due to the extremely moist climate and lower elevation of the site in relation to its common montane range. High abundances of *T. metensiana* imply that the climate became cooler and moister during its establishment because this species typically grows in higher latitudes and altitudes with greater precipitation (Jones *et al.* 2009).

The overall vegetation reconstruction (Fig. 2) produced three large changes in the assemblage from 10,500 cal BP until approximately 300 cal BP. From 10,500 – 10,100 cal BP there was a high abundance of aquatic and riparian plant types, as well as other wet-adapted species such as willow (*Salix*), alder (*Alnus*), and birch (*Betula*). This is generally associated with high levels of precipitation and moisture as well as warmer conditions. Following the decline of those wet species we see a dominance of alder with increases in grasses and rose until 3,500 cal BP, indicating that climate was becoming more dry (Jones *et al.* 2007). Finally, the arrival and expansion of conifers indicates that conditions became moister and much cooler (Jones *et al.* 2007).

I predict a low fire frequency (600 – 1000 years) prior to the arrival of black spruce in this site. Low fire frequencies could be due to insufficient fuel loads, or high precipitation levels.
cause fuel to be too moist for ignition. I therefore predict that any change in fire frequency (specifically an increase) should correspond with the arrival of black spruce. That is, if the frequency and abundance of “peaks” in the charcoal record increase, that increase should correspond with the arrival of black spruce.

I hypothesize that charcoal peaks will coincide with abrupt changes in vegetation as shown in the pollen diagram (Fig. 2). These rapid vegetation changes will be characterized by a sharp decline in plant species as opposed to a smooth decline; we can assume that a fire event is the cause of the abrupt change in vegetation. One possible change occurring after such an event could be an increased abundance in successional or pioneer species.

**Timeline**

November 2011-January 2012: Enumeration of charcoal particles in all samples.

February 2012-April 2012: Analysis of charcoal data, comparison to pollen data and the writing of the scientific paper to publish the study.

**Literature Cited**


Appendix

Fig. 1. Sediment characteristics of the Whitshed core including sediment type, core length, and obtained carbon dates.
Fig. 2. Pollen diagram showing the results of previously performed pollen analysis.