

Palynology and Paleoecology at Kilgii Gwaay Archaeological Site, Southern Haida Gwaii

by

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B.A. (Geography), University of the Fraser Valley, 2012

Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

in the
Department of Biological Sciences
Faculty of Science

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SIMON FRASER UNIVERSITY

Fall 2014

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Abstract

Buried pond sediments at the Kilgii Gwaay archaeological site on Ellen Island in Gwaii Haanas National Park were analyzed palynologically to produce a high-resolution record of postglacial vegetation during late glacial and early Holocene time. Seven AMS radiocarbon dates provide a sediment core chronology spanning the period 14,470-10,870 cal yr BP. Four biostratigraphic zones are defined, with a transition from early herb-shrub tundra (14,510 cal yr BP) to a *Pinus*-dominated forest 14,000 cal yr BP. *Pinus* is largely replaced by *Picea* 13,290 cal yr BP, followed by establishment of *Tsuga heterophylla* 12,420 cal yr BP. Changes in vegetation assemblages and stratigraphy may indicate cooling associated with the Younger Dryas event. Charcoal analysis reveal peak abundance during the known occupation of Kilgii Gwaay (10,700 cal yr BP). Charcoal extends below the known occupation horizon, indicating human presence as early as 11,500 cal yr BP, approximately 800 years earlier than previously documented.

Keywords: Haida Gwaii; Younger Dryas; Postglacial vegetation; High resolution; Kilgii Gwaay; archaeology; pollen; charcoal

Acknowledgements

I would like to express my deep gratitude to Rolf Mathewes, my senior supervisor, for his continual support and guidance throughout this project, and whose expertise was invaluable. Also, thanks to Elizabeth Elle, who is also on my supervisory committee, for her thoughtful feedback and revisions in preparing this thesis. The project would not be possible without Daryl Fedje, who collected the sediment core and gave permission to include a figure of Kilgii Pond. Also, thanks to Terri Lacourse for her help in conducting magnetic susceptibility analysis and providing data. Thanks to Matt Huntley for his help and friendship while working in the lab. I'd like to extend my thanks to Jonathan Hughes, who first sparked my interest in paleoecology and provided mentorship throughout my undergraduate education. Lastly, thank you to my family for providing endless support and encouragement.

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List of Acronyms

AMS	Accelerator mass spectrometry
asl	Above sea level
BP	Before 1950
Cal yr	Calibrated year
CONISS	Constrained Incremental Sum of Squares
MOC	Meridional overturning circulation
PNW	Pacific Northwest
THC	Thermohaline circulation

Chapter 1.

Introduction

Coastal forests characteristic of the Pacific Northwest represent one of the most productive and extensive temperate rainforests globally (Pojar and Mackinnon 1994). Development of these forests is highly dependent on successional processes driven by disturbance, climate and biological interactions. The high genetic diversity in these coastal forests is attributed to their longevity as well as proximity to areas of refugia that persisted during glaciation (Pojar and Mackinnon 1994). The modern forests we see along the coast have undergone considerable changes in structure and composition since reestablishment of vegetation following the last glaciation. Changes in vegetation communities following glaciation can be attributed to complex interactions between climate change and biogenic factors. Both long term climatic amelioration as well as shorter, discrete climate events have influenced vegetative succession during the last (Fraser) glaciation and during the postglacial.

Approximately 12,900-11,500 cal yr BP, a climatic event known as the Younger Dryas occurred, in which climatic warming following the last deglaciation was interrupted by rapid and intense cooling (Eisenman *et al.* 2009; Pinter *et al.* 2011). This event led to near-glacial conditions in some regions, however the extent of cooling varies geographically (Meltzer and Holliday 2010). Strong evidence for cooling in paleoecological records has been found throughout Europe and eastern North America, however it remains uncertain if the Younger Dryas was a global event (Peteet 1995; Mathewes 1993; Mathewes *et al.* 1993; Fedje *et al.* 2011; Walker and Pellatt 2003).

In the Pacific Northwest, several sites have shown evidence for cooling during the Younger Dryas as expressed in paleoecological records (Mathewes 1993; Hansen and Engstrom 1996; Lacourse 2005; Galloway *et al.* 2009; Ager *et al.* 2010), however at other sites the signal is weak or absent (Lacourse *et al.* 2012). Haida Gwaii, an

archipelago on the north coast of British Columbia (Figure 1.1) is one region in which conflicting paleoecological records exist with respect to how vegetation responded to this event and whether or not it is detectable (Fedje *et al.* 2011). For example, some studies have found pollen records to be indicative of cold and dry conditions, while others conclude that the climate was cool and wet (Fedje *et al.* 2011). Although a number of paleoecological studies have been conducted in the Pacific Northwest, many are based on small numbers of samples, are poorly dated, have low taxonomic resolution or include samples from problematic sites (Hansen and Engstrom 1996; Lacourse *et al.* 2012). More high-resolution studies with well-dated chronologies are needed on the western coast of B.C. to reconcile how and to what degree the Younger Dryas impacted vegetation dynamics in the post-glacial period (Walker and Pellatt 2003).

This study investigates the paleoecology of a late-glacial site in southern Haida Gwaii and compares it to other contemporaneous records in the region to assess vegetation succession and climate over time. The three main objectives of this study are to:

- 1) construct a long-term high-resolution record of vegetation establishment and succession following the last (Fraser) glaciation and compare the record to others on Haida Gwaii;
- 2) interpret the vegetation and charcoal record of an archaeological site that coincides with early human coastal occupation;
- 3) determine if a signal for the Younger Dryas cooling event is present at the site and help resolve uncertainties regarding how this event is expressed in the Pacific Northwest.

1.1. Paleoecology

Paleoecology, or the study of past ecology, looks at how organisms in the past interacted with their environment. Fossil assemblages of organisms along with sediment characteristics serve as proxies for interpreting past environmental conditions such as climate and forest composition. One of the limitations inherent in paleoecology is that reconstructions are limited to what is preserved in the fossil record.

Palynology or pollen analysis is a well known technique to study vegetation history and climate change (Faegri *et al.* 1989, Moore *et al.* 1991). Following production and dispersal, a portion of the pollen grains will fall to the ground and become deposited in sediment. When pollen is deposited in anaerobic environments, such as lakes, bogs and the sea, it becomes preserved and can be later extracted to determine vegetation history. Paleoecological records not only provide an invaluable record of long-term vegetation establishment and succession, but also serve as a proxy for how past climatic changes influence vegetation dynamics.

1.2. Younger Dryas Event

The Younger Dryas was a short period of time from 12,900 to 11,500 cal yr BP, in which climatic warming following the last major deglaciation was interrupted by rapid and intense cooling (Eisenman *et al.* 2009; Pinter *et al.* 2011). During the Younger Dryas, climatic conditions reverted to those similar to the last glaciation. Evidence for Younger Dryas cooling in the Pacific Northwest has been detected in glacial landforms, pollen assemblages and other climate proxies, but signals are regionally variable (Mathewes *et al.* 1993; Friele and Clague 2002; Fedje *et al.* 2011).

Although the Younger Dryas is well documented, the driving mechanism has been controversial. One hypothesis is that during deglaciation large amounts of freshwater flowed into the Atlantic Ocean via the St. Lawrence River system, which interfered with the Atlantic Ocean's meridional overturning circulation (MOC), also known as the thermohaline circulation (Rooth 1982; Broecker *et al.* 1989; Eisenman *et al.* 2009). Freshwater has a higher freezing temperature and is less dense than saltwater

and therefore a large influx of freshwater into the Atlantic could lead to freezing, preventing surface water from sinking and temporally slowing or shutting down MOC (Brocker *et al.* 1989; Eisenman *et al.* 2009). The source of this freshwater may have been Lake Agassiz, a large proglacial lake that covered 1.5×10^6 km² of what is now central Canada following deglaciation (Brocker *et al.* 1989). There has, however, been some controversy surrounding the source of freshwater that disrupted Atlantic MOC, and other research has suggested alternative freshwater influx routing (Eisenman *et al.* 2009; Meltzer and Holliday 2010). In addition, an extraterrestrial impact hypothesis has been suggested to be the cause of ice-sheet destabilization which led to disruption of the MOC. This hypothesis, however, has been criticized in recent literature due to unreproducible results (Pinter *et al.* 2011; Tian *et al.* 2011). Younger Dryas cooling attributed to Atlantic MOC disruption, is well established in records from Europe and eastern North America; however its global impact is not as clear (Mathewes *et al.* 1993; Fedje *et al.* 2011; Walker and Pellatt 2003).

1.3. Regional Setting of Haida Gwaii

Haida Gwaii is an isolated archipelago off the central coast of British Columbia, on the western edge of the continental shelf. It is one of the largest, most isolated archipelagos in western North America and consists of two large islands (Graham and Moresby) in addition to over 200 smaller islands with a total area of ~ 10,000 km² (Figure 1.1). The maritime environment of Haida Gwaii is controlled by the Pacific Ocean to the west, Hecate Strait to the east and Dixon Entrance to the north. Physiographic regions of Haida Gwaii include the Queen Charlotte Range on Moresby Island and southwestern Graham Island, and the Coastal Trough, which includes the Hecate Depression (Barrie *et al.* 2005; Holland 1976). Proximity to the Pacific Ocean has a moderating effect on climate, making summers relatively cool and winters mild. Mean annual precipitation can differ dramatically between the west and east coasts of the islands due to the orographic effect of the Queen Charlotte Range, ranging from 1200 mm on the northeast coast of Graham Island to over 4200 mm on the west coast (Hogan and Schwab 1990).

Biogeoclimatic zones of Haida Gwaii include the Coastal Western Hemlock (CWH), Mountain Hemlock (500-900 m asl) and Coastal Mountain-heather Alpine

(above ~900 m asl). The majority of the islands fall within the Central Very Wet Hypermaritime (CWHvh) zone at lower elevations, which transitions into mountain hemlock and alpine tundra at higher elevations. Much of the area west of the Queen Charlotte Range is within the subzone CWH Central Very Wet Hypermaritime (CWHvh3), a CWHvh variant unique to Haida Gwaii that accounts for 40% of the islands total land area. Arboreal taxa such as *Picea sitchensis*, *Tsuga heterophylla*, *Thuja plicata* and *Alnus rubra* are characteristic of this subzone. The forests of Haida Gwaii lack the mainland species *Abies amabilis* and *Pseudotsuga menziesii* (Banner *et al.* 2013).

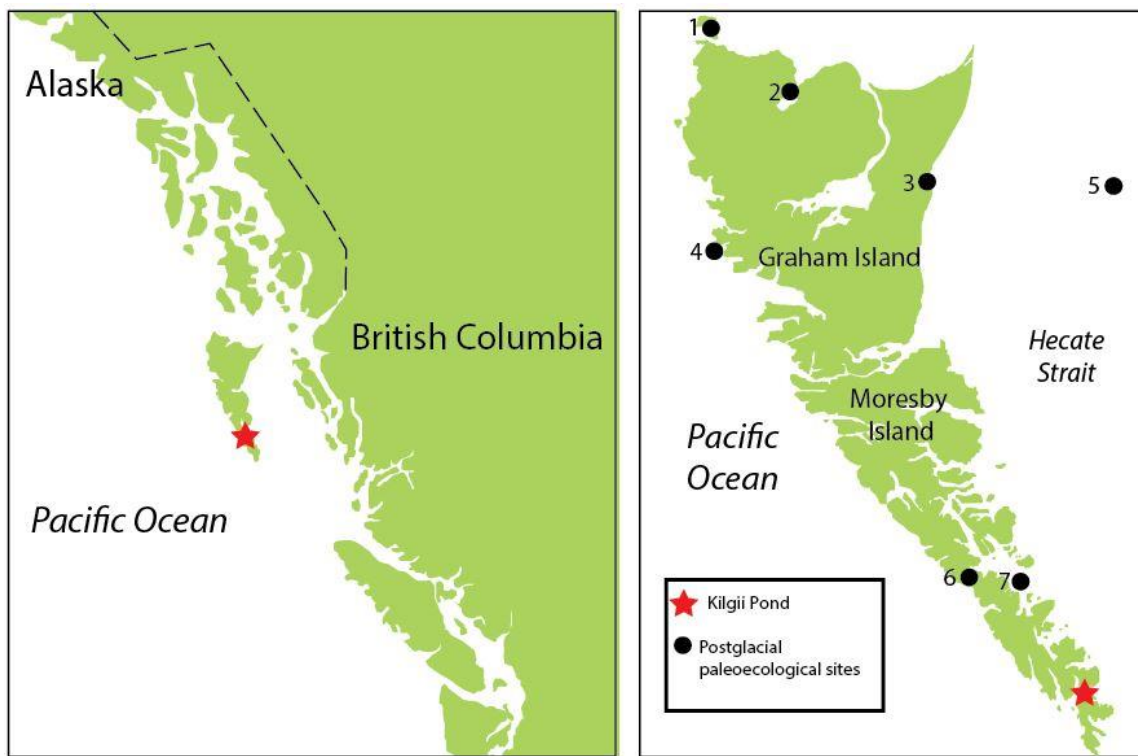


Figure 1.1 Map of the Pacific Northwest region (left) and Haida Gwaii (right). The red star indicates Kilgii Pond and black dots mark the following late glacial paleoecological sites: 1. Langara Island (Heusser 1995); 2. Mary Point (unpublished) 3. Cape Ball (Mathewes and Claugé, 1982); Mathewes *et al.* 1993); 4. Hippa Island (Lacourse *et al.* 2012); 5. Dogfish Bank (Barrie *et al.* 1993); 6. West Side Pond (Lacourse *et al.* 2005); 7. Juan Perez Sound (Lacourse *et al.* 2003).

Haida Gwaii archipelago has a diverse assemblage of endemic flora and fauna. It has been argued the early establishment of vegetation in northern Haida Gwaii 19,240 cal yr BP (16,000 ¹⁴C yr BP) indicates a nearby area that supported refugial points, however such an area has yet to be discovered (Warner *et al* 1982). Isolation could have led to divergence from the mainland taxa, contributing to the abundance of contemporary endemic taxa on the islands. Geological evidence now suggests that most of Haida Gwaii was covered by glacier ice during the last glaciation and that it is more likely that portions of the adjacent continental shelf in Hecate Strait were exposed subaerially and not ice-covered, providing refugia for flora and fauna (Barrie *et al.* 1993). Pollen and plant macrofossil evidence shows the presence of a productive herb-shrub tundra 16,650–15,900 years ago on the continental shelf, however a continuous paleoecological record that encompasses the entire Wisconsin glaciation has not yet been found (Barrie *et al.* 1993; Lacourse *et al.* 2005).

1.3.1. Glaciation and Sea-level Change

The last main phase of the Wisconsin glaciation (Fraser glaciation in B.C.) began ~25,000-30,000 year ago (Clague 1981). During Fraser glaciation, most of British Columbia was covered by the Cordilleran ice sheet (Clague 1981). During the climax of the Fraser glaciation, an independent ice cap was present on Haida Gwaii that coalesced with the Cordilleran ice sheet (Sutherland and Brown 1968; Clague *et al.* 1982). Ice coverage on Haida Gwaii was less extensive than the mainland and deglaciation occurred earlier than the mainland. The lowlands of Haida Gwaii and adjacent offshore areas, including Queen Charlotte Sound and Hecate Sound, were mostly ice free by 15,630 cal yr BP, compared to the mainland where ice persisted in some areas until ~11,000 cal yr BP (Barrie and Conway 1999; Blaise *et al.* 1990; Barrie *et al.* 2005).

Haida Gwaii is a region defined by a dynamic history of deglaciation and sea-level fluctuation. Postglacial sea level change experienced in Haida Gwaii and the adjacent offshore areas can be attributed to a combination of eustatic, glacio-isostatic and diastrophic factors (Clague 1981). Sea-levels during early postglacial time were relatively lower than present levels (Clague 1981). During and after Fraser Glaciation,

the coast of B.C. experienced substantial relative sea-level fluctuations due to tectonic uplift and isostatic depression. The presence of ice on the mainland created a forebulge on the outer coast, causing Haida Gwaii to be uplifted and portions of Hecate Strait to become subaerially exposed during glaciation (Barrie *et al.* 2005). Uplift from the forebulge and low eustatic sea levels caused a lowering of relative sea level of as much as 150 m ~14,000 cal yr BP (Josenhans 1997; Barrie and Conway 1999; Shugar *et al.* 2014). When ice began to retreat from the continental shelf, isostatic rebound, collapse of the peripheral forebulge and rapidly rising eustatic sea level from meltwater pulses associated with deglaciation, lead to rapidly rising relative sea-levels (Fairbanks 1989; Josenhans *et al.* 1995; Hetherington 2003). Between 12,200-11,000 cal yr BP sea-level was rising ~6.3 cm annually and eventually reached and then exceeded present-day sea-level by ~10,630 cal yr BP (Clague *et al.* 1982; Fedje *et al.* 2005). In addition, sea-level was much higher than present day levels throughout middle and late postglacial time, likely from diastrophism from the regions close proximity to the strike-slip Queen Charlotte-Fairweather fault zone (Clague 1981; Shugar *et al.* 2014).

Chapter 2.

Kilgii Gwaay

2.1. Archaeological site

The Kilgii Gwaay archaeological site is located on Ellen Island, in the southern portion of the Gwaii Haanas National Park, approximately 70 km from the B.C. mainland (Figure 1.1). The island is approximately 20 hectares in area, has a maximum elevation of 25 m and is located between Moresby Island to the north and Kunghit Island to the south (Fedje *et al.* 2001). The archaeological site is located in the intertidal zone of the southern portion of the island, and is periodically inundated although accessible at low tide.

The archaeological site was discovered in 1990 by Haida archaeologist Captain Gold. Over 1000 lithic surface artifacts have been found at Kilgii Gwaay (Fedje *et al.* 2005). A recent detailed study revealed an abundance of lithic artifacts, faunal remains and culturally modified bone (Fedje *et al.* 2001). Faunal remains found at the site include black bear, river otter, sea lion, seal, nine different species of bird and 11 species of fish (Fedje *et al.* 2005). Radiocarbon dates obtained from the site indicate occupation by humans ~10,700 cal yr BP (Fedje *et al.* 2005). At that time, sea level was at least 3 m below the present datum (Fedje *et al.* 2005).

Kilgii Gwaay is an important archaeological site as it contains one of the oldest known coastal shell middens in the Americas and provides evidence for early marine adaptation (Fedje *et al.* 2005). Human occupation was brief, between beginning around 10,700 cal yr BP and lasting ~50 years until the site was subject to a rapidly rising regional sea-level due to collapse of the peripheral forebulge (Fedje *et al.* 2005). The site completely inundated ~10,630 cal yr BP and has only become exposed in the past

5,000 years and is only accessible at low tide (Fedje *et al.* 2005). The samples collected for this study were taken from a pond (Figure 2.1) at the Kilgii Gwaay site that became buried with shell hash, gravel, sand and boulders following the early Holocene marine transgression. The Kilgii Pond core analyzed in this study provides a perspective into the paleoenvironment that existed during early human occupation on the coast. It is also a unique site as the core extracted for this study comes from a significant archaeological site.

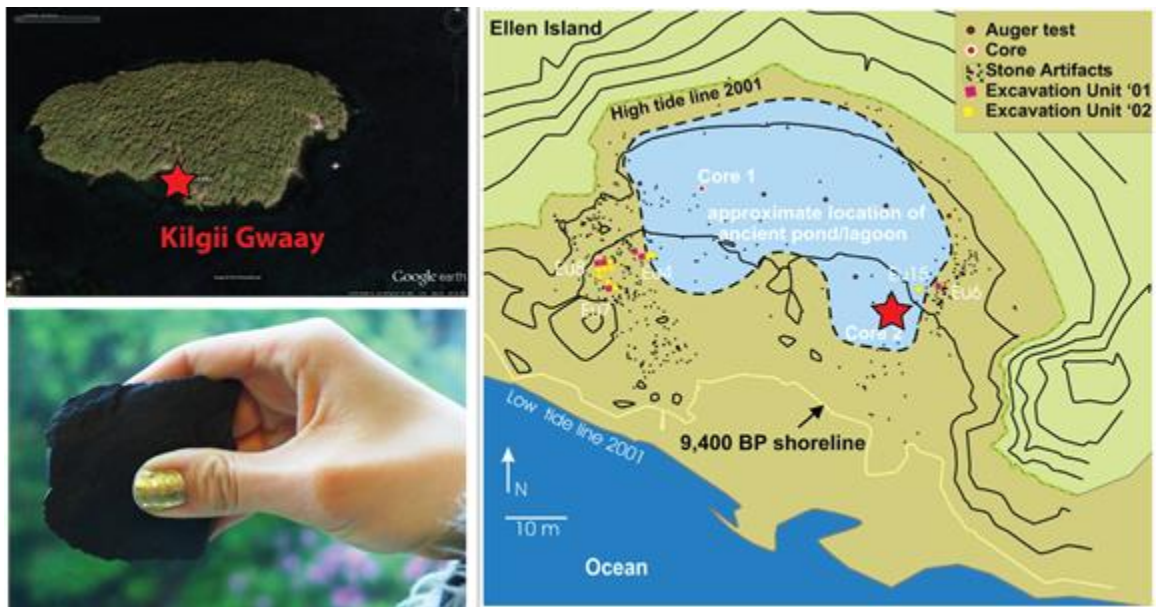


Figure 2.1 Ellen Island in Gwaii Haanas National Park, southern Haida Gwaii (top left) (modified from Google Earth 2013); and Kilgii Pond (right); and a lithic artifact from Kilgii Gwaay archaeological site (bottom left). Buried sediments of Kilgii Pond are located in the intertidal zone of Ellen Island (Fedje *et al.* 2001). The red star indicates the location of the analyzed pond core, and the dashed line delineates the margin of the pond.

Chapter 3.

Methods

3.1. Core Collection and Processing

Sediment from the fossil pond at Kilgii Gwaay was collected in 2001 by Daryl Fedje and co-workers. Approximately 50 cm of shell hash and gravel was removed from the modern surface beach and a percussion core 3 m long and 10 cm in diameter was extracted. The sediment core was split into two halves, cut into 3 segments, wrapped in plastic film and aluminium foil and placed into cold storage at 4°C. Magnetic susceptibility of the sediments was measured at 1 cm intervals using a Bartington MS2E surface sensor at the University of Victoria by Terri Lacourse. To avoid edge effects at the top and bottom of core segments, measurements within 1-2 cm of the sediment core ends were excluded from analysis.

3.2. Radiocarbon Dating and Age-depth Modelling

Eight macrofossils, including seeds, wood, and conifer needles, were extracted from selected levels for accelerator mass spectrometry (AMS) radiocarbon analysis. Three of the samples were submitted during this study to UCIAMS for analysis, and the samples dated by CAMS were provided by Fedje *et al.* from a previous study (2005). Radiocarbon ages were calibrated to calendar years using the IntCal09 calibration program in OxCal (Ramsey 2001). An age-depth model was produced from the radiocarbon ages using the Clam module of the software R (Blaauw 2010; R Development Core Team). A smooth spline was applied to the data set, and age estimates of each sample depth were determined by running the model at 10,000 iterations and taking the weighted mean of calibrated age ranges.

3.3. Pollen and Charcoal Analysis

3.3.1. Processing

Prior to subsampling at Simon Fraser University, 0.5 cm of outer sediment was removed from the split core half to avoid contamination. 81 samples were extracted at 2 cm intervals for microfossil analysis using a calibrated brass sampler. Volumetric displacement in water was used to take 5 ml samples of clay rich sediment at the base of the core. Samples were not taken above 50 cm in the upper portion of the core since it transitions into shell hash indicating mixing in the intertidal environment.

Palynomorphs were isolated from sediment subsamples using standard processing methods with some modifications (Faegri *et al.* 1989). Subsamples were transferred into 50 ml centrifuge tubes, and each sample received one tablet of exotic *Eucalyptus* pollen (16,180 \pm 1460, Batch # 903722). Hydrochloric acid (20%) was used to digest carbonates from the tablet and sediment. Hot 10% KOH was used to remove humic acids and disperse sediment. Large particles were removed using a 250 μ m sieve. Samples were then treated with hot 48% HF to remove silicates, followed by a hot 10% HCL rinse to prevent precipitates from forming. Acetolysis, using a 9:1 mixture of hot acetic anhydride and sulfuric acid, was used to remove cellulose, following dehydration in glacial acetic acid. Residues were washed several times with distilled water, followed by dehydration in successively higher concentrations of EtOH, ranging from 50-95%, ending with a tert-butyl alcohol rinse. Samples were then mixed into 2000 centistoke silicone oil and residues were mounted on microscope slides sealed with nail enamel. For samples with sparse palynomorphs, multiple slides of pollen residue were prepared. Charcoal in the upper portion of the core (86-48 cm) was also quantified for 16 pollen samples.

3.3.2. Quantification and Identification

Pollen and spores as well as charcoal fragments were counted at 400X magnification using a Zeiss compound microscope. Some palynomorphs were examined under oil immersion at 1000X magnification for identifications. All samples were counted

to a minimum sum of 300 pollen and spores. Identification of palynomorphs was aided by morphological keys (McAndrews *et al.* 1973; Moore *et al.* 1991; Kapp *et al.* 2000) and comparison with modern reference material from the SFU modern pollen collection. Taxa were then described using nomenclature from the Illustrated Flora of the Pacific Northwest (Douglas *et al.* 1998-2001). Scientific and common names of plant taxa are given in Table 3.1. Pollen and spore taxa were identified to species if distinguishing features were present, although most could only be identified to genus or family. Ericales included *Empetrum*-type and at least two other ericaceous taxa. All monolete fern spores with absent or non-distinct perine were classified as Filicales.

Charcoal fragments that were at least 25 μm in longest dimension, black and had sharp edges were tallied in two size categories, (25-100 μm and >100 μm). Charcoal fragments under 25 μm were not counted because they are often overrepresented in sediment that has been subject to pollen processing (Tolonen 1986). Small particles are also more subject to long-distance dispersal in the atmosphere than larger ones, which are more likely to have a local origin (Whitlock and Larsen 2001).

3.3.3. Pollen Percentages and Pollen Accumulation Rates

Count data were imported into the software program TILIA using Microsoft Excel files, converted into relative percentages and plotted as pollen diagrams (Grimm 2011). The pollen sum the sum of all terrestrial pollen and aquatic pollen. Nonpollen palynomorphs include fern, algal, and fungal spores, which were included in the total pollen sum plus nonpollen types in TILIA.

In addition to relative percentages, pollen accumulation rates (PARs) were calculated for each sample. Pollen accumulation rate (PAR) is a measure of the number of grains per unit area of sediment surface per unit time ($\text{cm}^{-2} \text{ year}^{-1}$) and reflects the quantity of pollen type independently of all others. PAR is more directly related to abundance of individual taxa as it is not affected by the abundance of other taxa, as percentages are.

To calculate PAR, the pollen concentration and sediment accumulation rate must be known for each sample. Pollen concentration refers to the number of pollen grains in

a given unit of sediment and sediment accumulation rate is the amount of sediment deposited annually. Pollen concentration was calculated in TILIA by dividing the number of fossil grains counted by the number of exotic (*Eucalyptus*) grains counted and then multiplying this value by the total number of exotics added. Sediment accumulation rate was determined using interpolated ages from the age-depth model and was calculated in TILIA by dividing sample thickness by the number of years per sample. The inverse of sediment accumulation rate, known as sediment deposition time, can also be used to calculate PAR, however sediment accumulation rate was used for this project.

3.3.4. Cluster Analysis

Zonation of biostratigraphy was determined using a constrained incremental sum of squares (CONISS) cluster analysis in TILIA (Grimm 2011). CONISS determines numerical zonation by calculating dissimilarity between all samples and grouping samples that are least dissimilar. It's a multivariate analysis technique that is constrained so that only stratigraphically adjacent samples cluster together (Grimm 1987). CONISS revealed four distinct biostratigraphic zones for the percentage pollen diagram.

Table 3.1: List of scientific and common names of plant taxa. Botanical nomenclature is in accordance to the Illustrated Flora of the Pacific Northwest (Douglas et al 1998-2001).

Family	Scientific Name	Common Name
Pinaceae	<i>Pinus contorta</i>	lodgepole pine
Pinaceae	<i>Picea sitchensis</i>	sitka spruce
Pinaceae	<i>Tsuga heterophylla</i>	western hemlock
Betulaceae	<i>Alnus rubra</i>	red alder
<hr/>		
Herbs and Shrubs		
Betulaceae	<i>Alnus viridis</i>	sitka alder
Cyperaceae		sedge
Poaceae		grass
Salicaceae	<i>Salix</i>	willow
Apiaceae		carrot family
Astereaceae		composite family
Astereaceae	<i>Artemisia</i>	sage
Ericales		
Nyctaginaceae	<i>Abronia latifolia</i>	yellow sand-verbena
Campanulaceae	<i>Campanula</i>	harebell
Caryophyllaceae		pink family
Onagraceae	<i>Epilobium</i>	fireweed
Liliaceae		lily family
Polygonaceae	<i>Polygonum bistorta</i>	common bistort
Ranunculaceae		buttercup family
Rosaceae	<i>Sanguisorba</i>	burnet
Valerianaceae	<i>Valeriana sitchensis</i>	sitka valerian
Viscaceae	<i>Arceuthobium</i>	dwarf mistletoe

Chapter 4. Results

4.1. Sediment Stratigraphy and Chronology

Eight macrofossils submitted for AMS radiocarbon dating from the Kilgii Pond core yielded ages ranging from 12,435 - 8670 ^{14}C yr BP (Table 4.1). The shell age yielded by the uppermost sample was corrected for the marine reservoir effect by subtracting ~600 years and yielded an age of 8670 ± 40 ^{14}C yr BP (9732-9540 cal yr BP) (Fedje *et al.* 2005). An *Arctostaphylos* seed (Figure 4.1) from the base of the core revealed a date of $12,435 \pm 35$ ^{14}C yr BP (14,968-14,153 cal yr BP) which marks the beginning of the record following deglaciation. The age-depth model constrained the predicted age of the sampled Kilgii Gwaay record to between 14,535 and 10,867 cal yr BP (Figure 4.2), spanning ~3600 years.

Five distinct stratigraphic units were identified in the core (Figure 4.2). The base of the core comprises of a bluish-grey clay that transitions upward into a brown gyttja with abundant woody debris at a depth of ~200 cm (13,864 cal yr BP). At 190 cm the gyttja is overlain by peat, which extends upward to ~70 cm. Woody debris is also present between ~185 and 160 cm. Above 70 cm the core is mixed terrestrial and intertidal sediment, which transitions into shell hash at ~30 cm depth and extends to the top of the core. Three discrete gravelly sand units occur at 74-76 cm, 87-89 cm and 102-104 cm the first being the most extensive (Figure 4.2). Magnetic susceptibility analysis revealed low organic content at the base of the core corresponding to the lowest stratigraphic unit. Organic content increases throughout the peaty unit and then decreases near the top of the core in the mixed terrestrial and intertidal unit. Two of the peaks in minerogenic material at 74-76 cm and 87-89 cm correspond to peaks in magnetic susceptibility (Figure 4.2).

Table 4.1: ^{14}C AMS age estimates obtained from macrofossils extracted from the Kilgii Pond. Calibrated age range and mean age (2σ) and have been calibrated in Oxcal using the IntCal09 calibration curve. All dates were funded through Parks Canada. CAM results are from Fedje *et al.* (2005) and UCIAMS were added during this study. A marine reservoir correction of -600 years was used on CAM-79685 (Fedje *et al.* 2005).

Laboratory #	Material	Depth (cm)	Radiocarbon Age (^{14}C yr BP \pm 1σ)	Calibrated Age
CAMS-79685	Sea urchin	20	8670 \pm 40	9732-9540 (9614)
CAMS-95558	Wood	79	10,025 \pm 40	11,750-11,321 (11,517)
UCIAMS-116603	Wood	110	10,890 \pm 35	12,906-12,634 (12,753)
UCIAMS-116602	Wood	161	11,415 \pm 35	13,392-13,167 (13,286)
CAMS-82214	<i>Pinus</i> needle	199	12,010 \pm 60	14,024-13,729 (13,866)
CAMS-82214	Seed	216	12,190 \pm 60	14,475-13,812 (14,040)
CAMS-95559	Seed	219	12,455 \pm 40	14,997-14,169 (14,559)
UCIAMS-116604	Seed	224.5	12,435 \pm 35	14,968-14,153 (14,511)

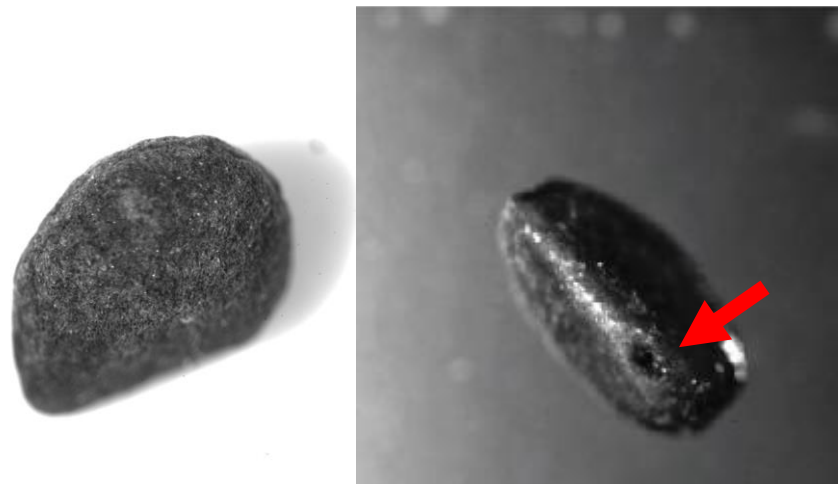


Figure 4.1: *Arctostaphylos* sp. seed extracted from basal sample of Kilgii Pond core dated at 12,435 \pm 35 ^{14}C yr BP (14,511 cal yr BP) (left). *Arctostaphylos* seed displaying funiculus scar (arrow).

4.2. Pollen Percentage Diagram

Pollen and spore data from Kilgii Gwaay are assignable four distinct biostratigraphic zones delineated by major breaks in the CONISS cluster analysis (Figure 4.3 and 4.4). The lowermost zone KG-1, includes 12 samples from the base of the core at 225 cm up to 195 cm. The middle zone KG-2 spans the interval from 195 to 158 cm and includes 16 samples. Zone KG-3 ranges 158 to 95 cm and includes 31 samples. The uppermost zone KG-4 extends from 95 to 48 cm and includes 22 pollen samples. Pollen and spore characterization of each zone are summarized below.

Zone KG-1: 14,520-13,770 cal years BP (225-195 cm)

This zone is characterized by very low percentages of arboreal pollen and a dominance of herb pollen. Cyperaceae is the most common taxon in basal samples and peaks at 220-221 cm, representing ~50% of the total pollen sum (TPS) at that level. Ericales pollen is present in high percentages in the middle of the zone comprising >60% of TPS, most of which is likely *Empetrum*. *Salix* is also abundant throughout Zone KG-1 with values of 6-30%. Other notable herbs include Poaceae (0-15%), Apiaceae (0.7-9%), *Artemisia* (0.3-4%), Asteraceae (Tubuliflorae) (0-1%) and *Sanguisorba* (2.6%). Although rare (<1%), herbs such as *Abronia*, *Campanula*, *Polygonum bistorta* and *Epilobium* suggests the local vegetation was a herb-shrub tundra, similar to that at other sites on Haida Gwaii (Mathewes 1993; Lacourse and Mathewes 2005). In addition, fern spores such as monolete Filicales and *Polypodium* (3-24%) are present in this zone. The planktonic alga *Pediastrum* (up to 9%) is also present in this zone, indicating aquatic conditions. Near the top of the zone *Pinus contorta* pollen increases and herbs and shrubs decrease.

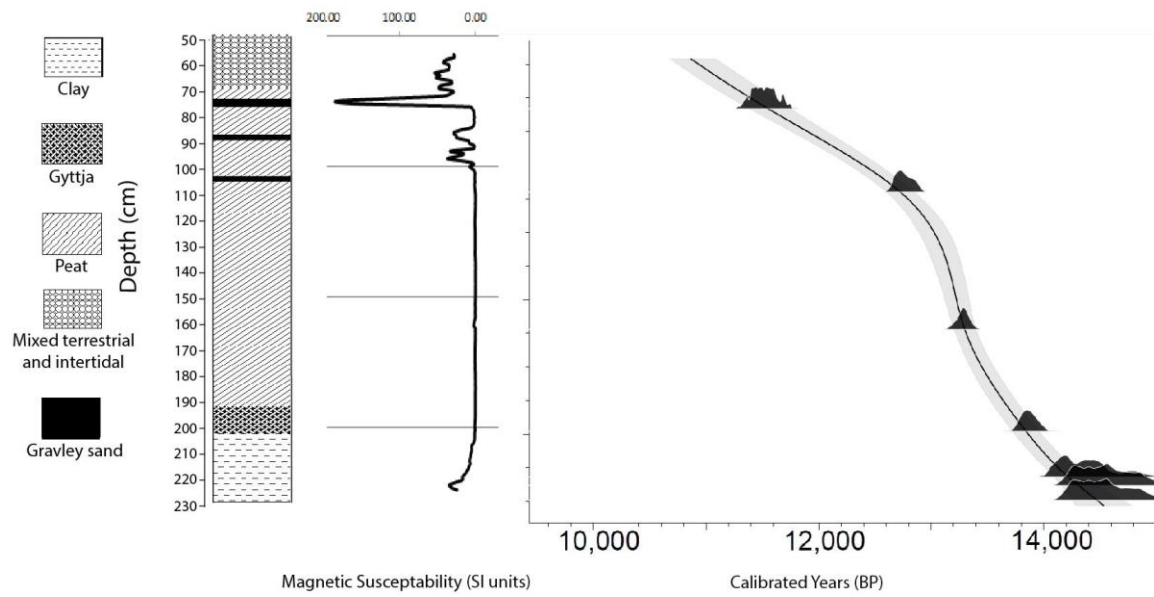


Figure 4.2: Sediment stratigraphy, magnetic susceptibility and age-depth model of Kilgii Pond sediment. Age-depth model was produced using the Clam module in the software R (Blaauw 2010; R Development Core Team). The model was run at 10,000 iterations. The grey portion of the line represents the 95% confidence interval and the black line is the smooth spline interpolation.

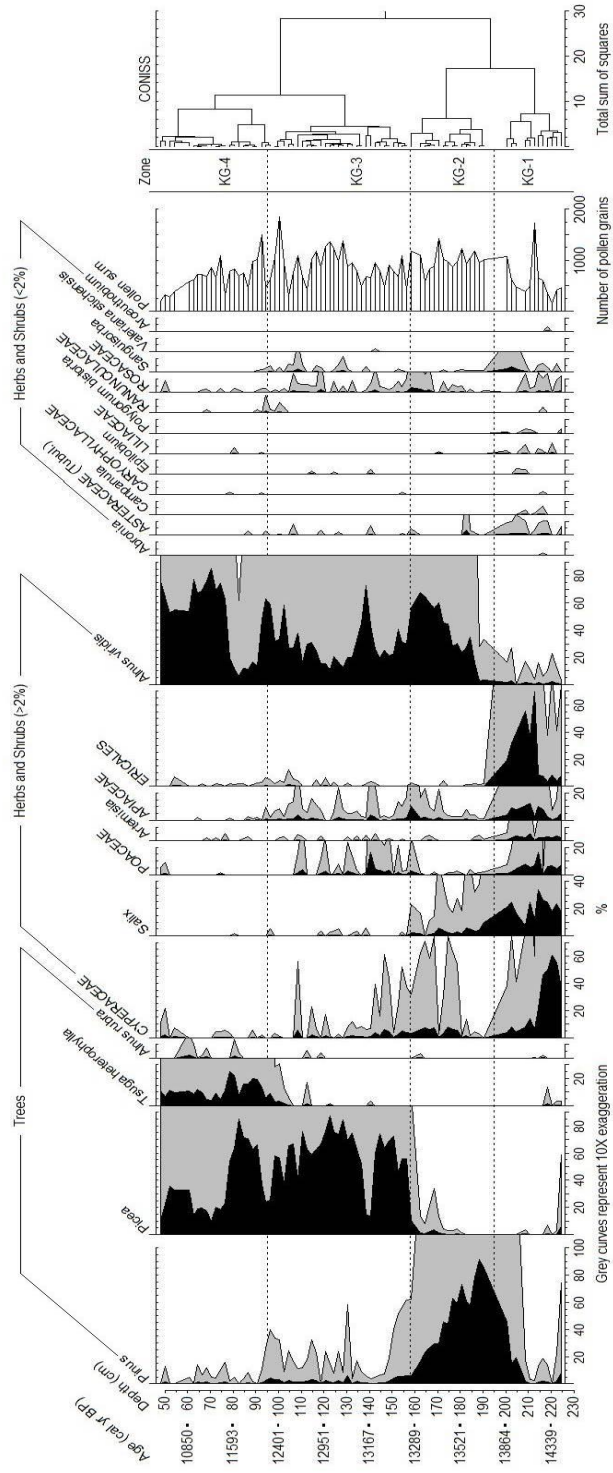


Figure 4.3: Pollen percentage diagram for Kilgii Pond and pollen zones determined by CONISS analysis. Grey curves indicate 10X exaggeration.

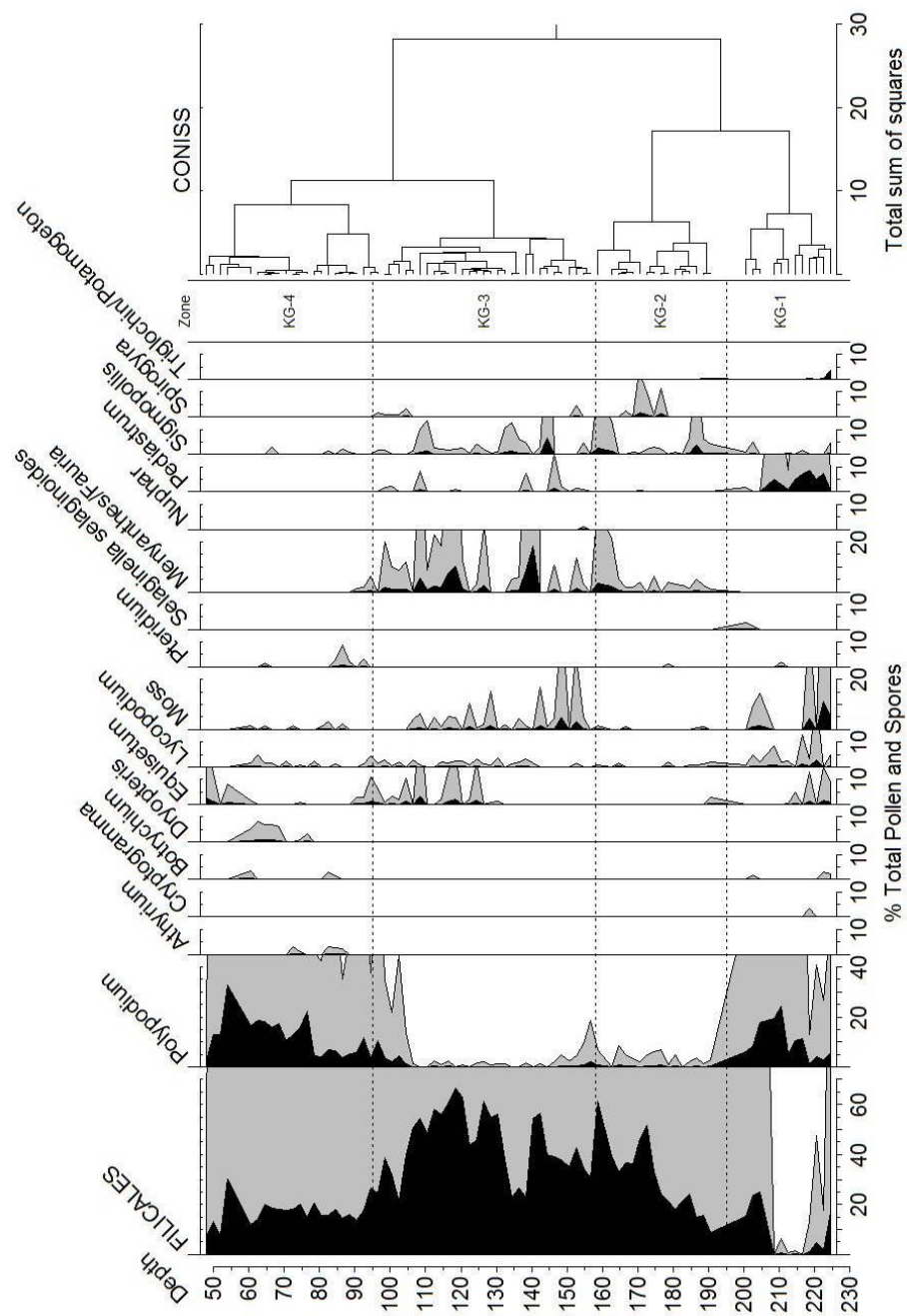


Figure 4.4: Relative percentage diagram of spores and aquatic pollen from Kilgii Pond and CONISS analysis. Grey curves indicate 10X exaggeration.

Zone KG-2: 14,500-13,270 cal years BP (195-158 cm)

Zone KG-2 marks a transition from herb-shrub tundra to a *Pinus*-dominated forest with reduced herb pollen. *Picea sitchensis* and *Alnus viridis* pollen percentages are high, ranging between 15-77% and 2-43%, respectively. Herb and shrub taxa such as Cyperaceae, *Salix*, Ericales, *Artemisia* and Apiaceae decrease substantially or completely disappear in this zone. Aquatic plants such as *Menyanthes* and a peak in *Spirogyra* algae, which peaks near the top of the zone indicate the continued presence of fresh water. Filicales spores increase from the bottom to top of the zone, indicating locally moist conditions.

Zone KG-3: 13,270-12,210 cal years BP (158-95 cm)

Pinus contorta pollen abruptly decreases in Zone KG-3 and is largely replaced by *Picea sitchensis* pollen, which reaches values up to 49%. *Alnus viridis* pollen peaks near the middle of the zone (134-140 cm) along with an increase in Poaceae pollen and other herbs. Cyperaceae persists in low percentages (<4%) throughout the lowermost half of the KG-3 zone but is absent in the upper-most samples. The presence of aquatic plants (*Menyanthes*, *Nuphar*) and freshwater algae (*Pediastrum*, *Sigmopollis*, *Spirogyra*) indicates the persistence of standing fresh water at the pond.

Zone KG-4: 12,208-10,456 cal years BP (95-48 cm)

The uppermost zone records a mixed *Picea sitchensis* and *Tsuga heterophylla* forest. *Picea sitchensis* continues to be a dominant taxon making up between 7 and 65% of the TPS. *Tsuga heterophylla* becomes established, contributing 1-19% to TPS. *Alnus viridis* is abundant in the lower and upper portion on the zone, contributing over 50% of the TPS, although it is lower in the middle of the zone (80-90 cm). *Polypodium* increases rapidly in this zone, likely reflecting the establishment of polypody ferns that are epiphytes associated with large trees. Herb pollen is low throughout KG-4.

4.3. Pollen Accumulation Rates

The PARs from Kilgii Pond shows a sequence of changes comparable to the percentage diagram (Figure 4.5). Total PAR (Figure 4.6) is low in the lowest zone of the record (14,518-13,772 cal yr BP) and is predominately related to herb and shrub taxa. *Salix*, Cyperaceae and Ericales have the highest PARs within this zone. PARs for herbs such as *Campanula*, *Abronia* and *Polygonum bistorta* appear sporadically in low amounts. PARs increase throughout zones KG-2 and KG-3, peaking at 136 cm and then decreasing in the uppermost zone KG-4. In zone KG-2, high PARs are largely attributable to *Pinus contorta*, *Salix*, and Cyperaceae. In contrast, PARs in zone KG-3 are largely driven by *Picea sitchensis*, Poaceae and Cyperaceae. PARs of Rosaceae, *Sanguisorba* and *Artemisia*, relative to other zones.

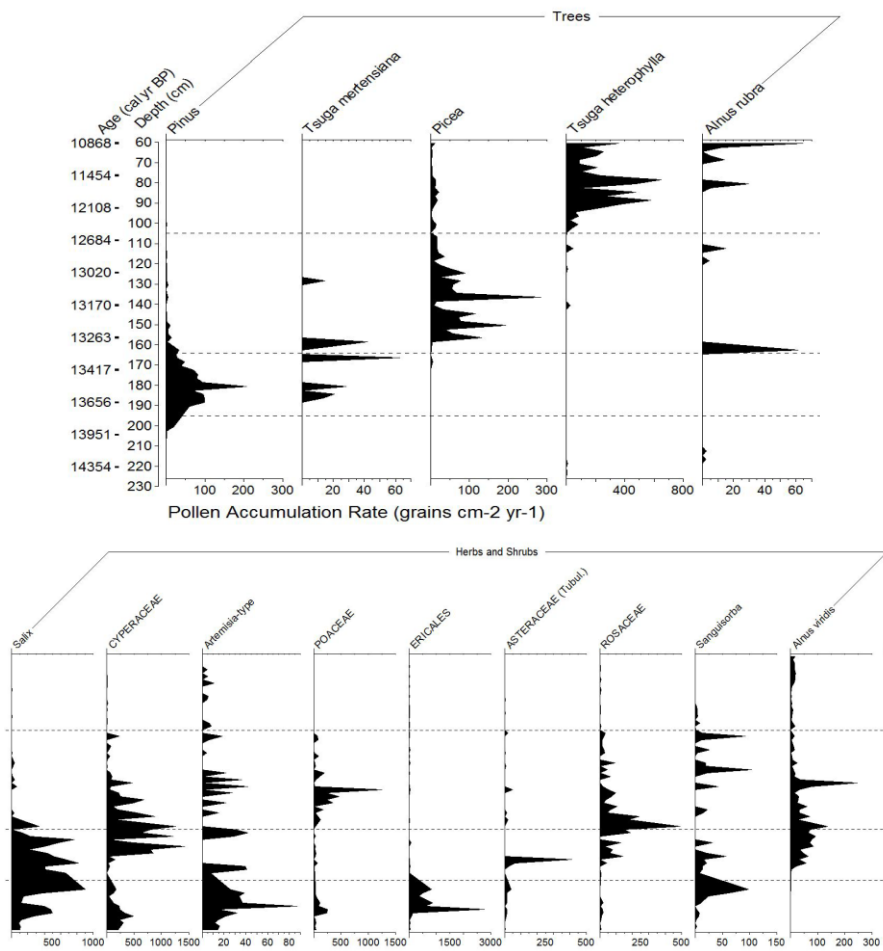


Figure 4.5` Pollen accumulation rate diagram for trees (top) and herbs and shrubs (bottom) of Kilgii Pond. Herbs and shrubs < 20 grains per cm⁻² year⁻¹ are not included in diagram.

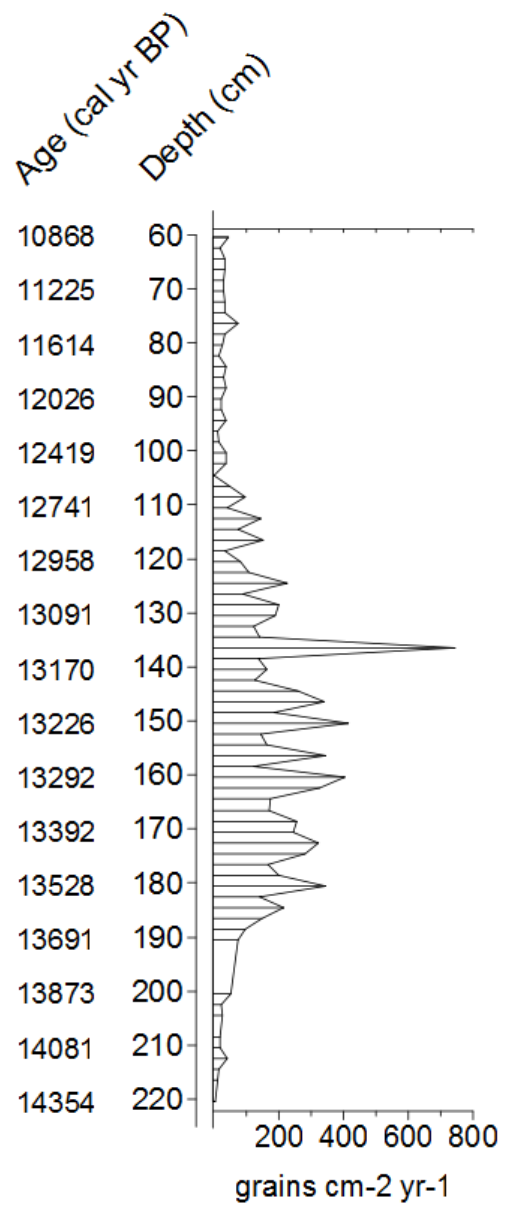


Figure 4.6: Total pollen accumulation rate (PAR) for all taxa.

4.4. Charcoal Analysis

Charcoal analysis reveals the presence of charcoal fragments $>100\ \mu\text{m}$ and 25- $100\ \mu\text{m}$ in all 13 samples between 48 and 80 cm (Figure 4.7). Both fragment size categories are strongly correlated, however fragments $>100\ \mu\text{m}$ are more indicative of local fire events (Tolonen 1986). The charcoal accumulation rate peaks notably at 54 cm followed by a smaller peak at 50 cm. These two peaks occur at 10,650 cal yr BP and 10,520 cal yr BP, respectively. Four samples below 80 cm were analyzed for charcoal fragments; however none was below 80 cm.

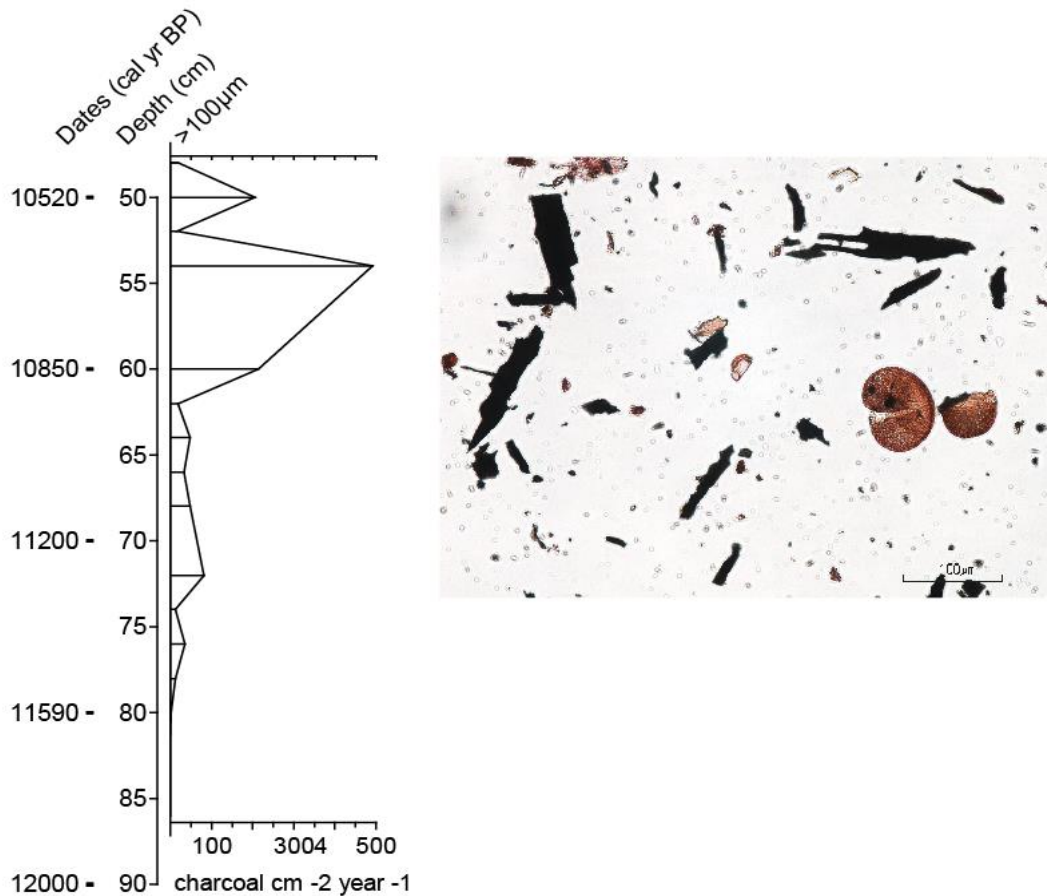


Figure 4.7: Accumulation rates of charcoal fragments $>100\ \mu\text{m}$ (left) and photograph of charcoal fragments present in the upper portion of the core (right).

Chapter 5. Discussion

5.1. Vegetation Establishment and Succession

The Kilgii Pond record is familiar to that at several other early postglacial sites in the region. Between 14,470-14,500 cal yr BP (225-195 cm), pollen evidence suggests a treeless herb-shrub tundra, representing the first vegetation assemblage following deglaciation. Although small amounts of *Pinus contorta* and *Picea sitchensis* pollen are present, they may represent pollen that was transported long distances, as stomata or macrofossils were not present to verify local presence. Taxa such as *Salix*, Cyperaceae, Ericales, and Poaceae dominate zone KG-1, along with a variety of rarer herbaceous taxa including *Abronia latifolia*, Asteraceae (Tub), *Campanula*, *Polygonum bistorta*. The presence of *Pediastrum* indicates the presence of fresh water. High percentages of *Polypodium* between 14,520 and 13,770 cal yr BP suggests ferns were common. The presence of herb-shrub tundra with subalpine indicators such as *Polygonum bistorta* and *Valeriana sitchensis* at early postglacial sites in the Pacific Northwest reflects a climate cooler than today. Although Ericales pollen was not differentiated at a high taxonomic level, the local presence of *Arctostaphylos* is verified by a seed (Figure 4.1). The abundant ericaceous pollen likely represents crowberry (*Empetrum*), a common dwarf shrub at early postglacial sites on Haida Gwaii (Mathewes 1989; Lacourse 1993). Some taxa, such as *Salix*, may be underrepresented due to low pollen production and dispersal rates (Heusser 1983). Rare *Abronia latifolia* pollen also suggests a sandy beach environment; it has been found at similar early postglacial sites on Haida Gwaii such as Mary Point and Cape Ball, and on the nearby continental shelf north of Vancouver Island (Lacourse and Mathewes 2005). Although *Abronia latifolia* is entomophilous and does not produce abundant pollen in comparison to anemophilous taxa, its pollen in the record indicates it was present at the site. *Abronia latifolia* now restricted to one known location on Graham Island, was once much more widespread. Similar vegetation assemblages of the same age can be found at other sites on Haida

Gwaii and on northern Vancouver Island (Mathewes *et al.* 1993; Lacourse *et al.* 2004; Lacourse *et al.* 2012;).

A transition from herb shrub tundra to pine-dominated forest with reduced herb and shrub coverage occurs within pollen zone KG-2 at about 14,500 cal yr BP (195 cm). Herb and shrub taxa such as Cyperaceae, *Salix*, Ericales, *Artemisia* and Apiaceae decrease substantially or completely disappear. The understory comprises mostly ferns (Filicales) and sitka alder. The transition in the vegetation record closely follows changes in sediment stratigraphy from a blue-grey clay into a brown gyttja with abundant woody debris at 200 cm, and into peat at ~190 cm. *Menyanthes* and *Spirogyra* algae indicate the local presence of fresh water. *Pinus* establishment at Kilgii Gwaay 14,500 cal yr BP is generally consistent with other records from Haida Gwaii (Mathewes *et al.* 1993; Lacourse *et al.* 2004; Lacourse *et al.* 2012) and other regional sites from southeastern Alaska and Vancouver Island (Hebda 1983; Hansen and Engstrom 1996; Ager *et al.* 2010).

The establishment of *Pinus contorta* and other arboreal taxa during postglacial time can be attributed in part to increasing temperature. The climate regime of the late-Pleistocene and early Holocene underwent rapid changes (Walker and Pellat 2013). During the Last Glacial Maximum the jet stream became displaced to the south due to the presence of the Laurentide and Cordilleran Ice Sheets, causing a cooling of the mid latitudes (Anderson *et al.* 1988; Bartlein *et al.* 1998; Walker and Pellat 2013). In addition, a glacial anticyclone high pressure system formed over the Laurentide and Cordilleran ice sheets, inducing katabatic easterly winds at the southern margin of the ice, leading to cold, dry air masses in coastal regions of the Northwest (Anderson *et al.* 1988; Bartlein *et al.* 1998; Walker and Pellatt 2013). Due to increased insolation, the ice sheets began to melt and the jet stream eventually shifted northward as the anticyclone weakened, allowing moist Pacific air to move onshore (Barnowsky 1987; Anderson *et al.* 1988). This led to more abundant storms and subsequently warmer and wetter conditions that favoured establishment of trees in the Pacific Northwest after 14,000 cal yr BP (Hansen and Engstrom 1996). The transition from herb-shrub tundra to *Pinus*-dominated forests throughout the region can be attributed to increased temperatures and precipitation after 14,000 cal yr BP.. In addition, *Pinus contorta* is able to reproduce rapidly in the absence

of competition and can easily colonize disturbed sites with poor or infertile soils (Fowells 1965; Heusser 1995; MacDonald *et al.* 1998). These adaptations compounded with appropriate edaphic and climate conditions allowed for rapid colonization of pine on recently unglaciated landscape throughout the region.

An abrupt transition in forest composition occurs 13,330 cal yr BP (164 cm), when open *Pinus contorta* forest was replaced by a closed *Picea sitchensis* forest. The understory is predominantly composed of *Alnus viridis* and Filicales, with herbs such as Poaceae, Cyperaceae and Apiaceae present in low percentages. Aquatic plants (*Menyanthes*, *Nuphar*) and algae (*Pediastrum*, *Sigmopolis*, *Spirogyra*) indicate standing freshwater. The transition from a *Pinus contorta*-dominated forest to a *Picea sitchensis* forest at Kilgii Gwaay occurs at about the same time as at other sites on southern Haida Gwaii and reflects similar vegetation succession within the region (Warner *et al.* 1982; Hebda 1983; Mathewes 1993; Hansen and Engstrom 1996; Lacourse and Mathewes 2005; Ager *et al.* 2010; Lacourse *et al.* 2012). For example, at other sites on Haida Gwaii, *Picea* appears by 13,800 cal yr BP at Hippa Lake (Lacourse *et al.* 2012), ~13,400 cal yr BP at West Side pond; and ~13,075 cal yr BP at Cape Ball (Mathewes 1993; Figure 1.1). At 12,590 cal yr BP, *Tsuga heterophylla* becomes established at Kilgii Pond and coexists with *Picea* as a mixed coniferous forest. *Alnus viridis* still dominates the understory, however there is a decrease in Filicales and an increase in *Polypodium* ferns.

Although *Pinus contorta* is an early colonizer, *Picea sitchensis* and *Tsuga heterophylla* are more shade-tolerant and therefore better able to compete in a mixed forest (Hansen and Engstrom 1996; Lacourse 2009). In addition, expansion of *Picea* was likely facilitated by early Holocene climate warming (Hansen and Engstrom 1996). From 10,190 to 7,810 cal yr BP (9000-7000 ¹⁴C yr BP), climate was dominated by moist, warm westerly winds that allowed *Tsuga heterophylla* to flourish (Anderson *et al.* 1988; Hansen and Engstrom 1996).

The uppermost pollen zone (KG-4. 12,590-10,870 cal yr BP) records a mixed *Picea sitchensis*-*Tsuga heterophylla* forest characterized by high percentages of arboreal pollen and low percentages of herb and shrub pollen, which reflect rising sea-levels and shading by dense forest cover. Sea level was rapidly rising and is reflected in

core stratigraphy by a transition from mixed terrestrial and intertidal sediment into shell hash at about 30 cm depth (Josenhans *et al.* 1995). Although *Picea sitchensis* and *Tsuga heterophylla* are present in the record at this time, they likely represent a regional vegetation signal, as most arboreal pollen is anemophilous and is overrepresented in records (Faegri *et al.* 1989). In addition, no arboreal stomata or macrofossil were present to indicate a local signal. Overall PARs for this zone are also low compared to zones KG-2 and KG-3 (13,328-12,591 cal yr BP), which also supports that loss of local vegetation productivity may be due to sea level drowning the site.

The driving forces behind postglacial vegetation succession involve complex interactions between climatic and biogenic factors. In addition to climate change and adaptations of taxa, phytogeographical factors dictated the timing of vegetation succession throughout the region. Early establishment of pine at Haida Gwaii suggests the presence of nearby glacial refugia that likely supported *Pinus contorta* and other taxa during glaciation (MacDonald *et al.* 1998; Lacourse *et al.* 2005; Hansen and Engstrom, 1996; Ager 2010). *Pinus* occurs at sites in Washington, south of glaciated areas, throughout the last glaciation (Barnosky 1981). Hansen and Engstrom (1996) argue that the early appearance of pine in the records from southeastern Alaska and Haida Gwaii is likely due to a nearby refugium, rather than the northward expansion of this taxa from the south.

5.2. Early Human Occupation

Charcoal fragments only occur in upper cultural samples of the Kilgii Pond record, and the largest peak in charcoal accumulation rate occurs at 10,680 cal yr BP, matching the known date of human occupation of Kilgii Gwaay at 10,700 cal yr BP. Charcoal is likely a proxy for human occupation, indicative of anthropogenic burning such as campfires for cooking and heat, given that the pond is a known archaeological site and fire during this time were rare. Most early Holocene sites in the region characterized by mixed *Picea* and *Tsuga heterophylla*, such as Kilgii Pond, were subject to very moist climatic conditions and natural fires were rare or absent in this hypermaritime climate (Brown and Hebda 2003). Assuming that Kilgii Pond charcoal is anthropogenic, the presence of fragments >100 µm at 80 cm suggests human

occupation may have begun as early as 11,590 cal yr BP, or approximately 800 years earlier than previously thought. Current archaeological evidence for early human occupation of the islands is limited to a few sites, of which the earliest 12,650 cal yr BP at a cave site used for winter bear hunting (Fedje *et al.* 2011), suggesting that an earlier date of occupation at Kilgii Gwaay is plausible.

The pollen record during human occupation shows the presence of a mixed *Picea* and *Tsuga heterophylla* forest with abundant *Alnus viridis*. Other taxa present in smaller percentages include *Alnus rubra*, Cyperaceae, Poaceae and Rosaceae. In addition, Filicales and Polypodium spores were abundant at this time. Although taxonomic resolution of pollen is somewhat limited, the local presence of taxa such as *Sambucus racemosa*, *Rubus* sp., *Rubus parviflorus*, *Rubus spectabilis*, Isoetopsida, *Cornus* sp., *Gaultheria shallon*, *Carex* spp., *Vaccinium* sp., Amaranthaceae (*Atriplex* sp. Cf.), *Conioselinum gmelinii*, Asteraceae, *Juncus* sp., *Chara* sp., *Prunus* sp., and *Menziesia ferruginea* have been verified by the presence of plant macrofossils (J. Cohen, personal communication, 2014; unreferenced).

The collection of lithic artifacts and faunal assemblages discovered at Kilgii Gwaay shows that early humans were already well adapted to the marine environment, based on the presence of albatross, various fish, and other marine organisms. The shell midden at Kilgii Gwaay represents the oldest known coastal shell midden on the North Coast (Fedje *et al.* 2001). In addition, it is a significant site as very few early Holocene sites on the Northwest Coast have such extensive faunal assemblages (Fedje *et al.* 2001). Kilgii Gwaay was a summer hunting site, and along with Richardson Island to the north, provides the earliest evidence for marine adaptation on the islands (Fedje *et al.* 2011). Further evidence for early marine adaptation comes from On Your Knees Cave in southeastern Alaska, where isotopic $\delta^{13}\text{C}$ values from human remains show a predominantly marine diet (Fedje *et al.* 2011).

The evidence for marine adaptation of early humans on the coast further supports the hypothesis for a coastal route of migration into the mid-latitudes of the Americas following migration across the Beringia. Although the ice-free corridor model for migration has been prominent in literature since it was proposed in the 1930's,

evidence from geological, paleoecological, genetic and other studies suggest the coastal route would have been a more viable path (Mathewes 1989; Mandryk *et al.* 2001; Fagundes *et al.* 2008). Furthermore, cosmogenic nuclide analysis on glacial erratics has revealed that an ice-free corridor did not exist at the maximum of the last glaciation during the time when humans would have migrated (Jackson *et al.* 1997). Although no direct evidence of a coastal migration through the Pacific Northwest, such as watercraft remains, has been found, it is likely that rapidly rising sea levels in the Holocene and related erosion have limited visibility of archaeological sites along the coast (Clark and Mix 2002; Fedje *et al.* 2011). These additional sites may add evidence to resolve the route of migration.

5.3. Younger Dryas

5.3.1. Kilgii Pond Record

The age-depth model constrains the Younger Dryas chronozone (12,900-11,500 cal yr BP) to 78-119 cm in the Kilgii Pond record. This chronozone falls between zones KG-3 and KG-4 when pollen transitions from *Picea sitchensis*-dominated forest to a mixed *Picea-Tsuga heterophylla* forest. Typical signals in pollen records from the Pacific Northwest that have been interpreted as cooling related to the Younger Dryas include changes from forests to herbs and shrubs, increases in *Picea sitchensis*, *Tsuga mertensiana*, *Alnus viridis* and decreases in PARs.

Kilgii Pond exhibits a decline in spruce and an increase in *Alnus viridis* which may be interpreted as a subtle response to cooling. There is no strong shift in the vegetation assemblage, such as a return to herb-shrub tundra or increased *Tsuga mertensiana*. Also Kilgii Pond exhibits low PARs in samples from 119 to 190 cm, a characteristic that has been attributed to cooler conditions during the Younger Dryas due to lowered plant productivity. Sediment stratigraphy and magnetic susceptibility analysis revealed three discreet sand units at 74-76 cm (11,400 cal yr BP), 87-89 cm (11,900 cal yr BP), and 102-104 cm (12,500 cal yr BP), all of which encompass Younger Dryas-aged sediment. Increased minerogenic and reduced organic content have been interpreted at other PNW sites as a signal of Younger Dryas cooling (Hansen and Engstrom 1996). It

is unclear whether these minerogenic layers are the result of the Younger Dryas. The presence of such deposits may be related to other processes such as mixing during sea level rise. Given that Haida Gwaii is located in a seismically active region, it is possible that one or all of these minerogenic layers may be related to tsunami events.

Subtle changes in the vegetation assemblage paired with low PARs, and reduced organic matter, provide evidence for a weak cooling signal in Younger Dryas-aged sediment. The record, however, does not show any substantial changes, such as a return to herb-shrub tundra, found at other Pacific Northwest sites.

5.3.2. The Younger Dryas Event on the Pacific Northwest Coast

Fedje *et al* (2011) recently reviewed the Younger Dryas record at sites in the Pacific Northwest and Pleasant Island and Mitkof Island in southeast Alaska that show floristic changes in the paleoecological records that correspond with the Younger Dryas chonozone (Figure 5.1 and 5.2). A pollen record was extracted from a small kettle lake at the Pleasant Island site and a well-dated chronology based on 10 bulk radiocarbon ages and 6 AMS ages constrained the record to between 14,600 and 7,500 cal yr BP. Six distinct pollen zones show a transition in vegetation from late glacial shrub-dominated tundra, to pine-dominated parkland, to *Alnus* shrub-lands and eventually to contemporary vegetation that consists of coastal forest and *Pinus contorta* muskeg. In zone three of the pollen diagram, between 12,600 to 11,300 cal yr BP, there is a dramatic return to tundra-like vegetation communities comprising taxa such as *Artemisia*, Poaceae, Cyperaceae, *Sanguisorba*, and *Selaginella selaginoides* along with a decrease in *Pinus contorta* and shrub alder. In addition to this major change in vegetation, there is a decrease in organic matter and an increase in mineral deposition in this zone, which may relate to reduced vegetation cover. Overall, records from Pleasant Island show strong evidence for a cooler and drier environment during the Younger Dryas (Hansen and Engstrom 1996). This may be similar to the minerogenic pulses present at Kilgii Pond.

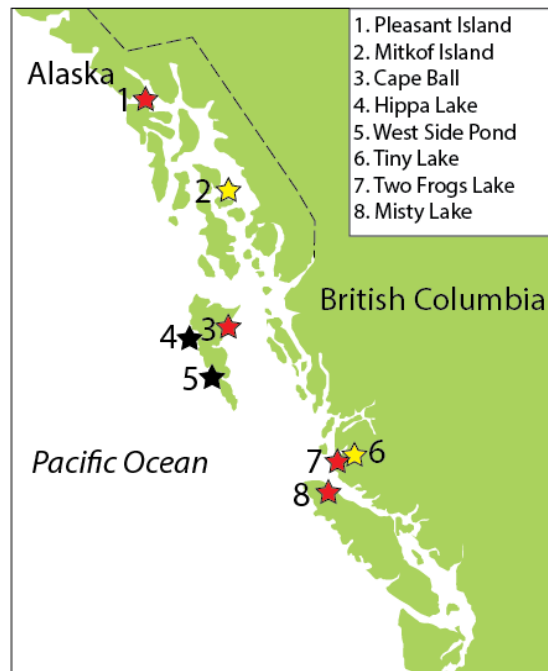


Figure 5.1 Younger Dryas-aged sites along the Pacific Northwest coast.

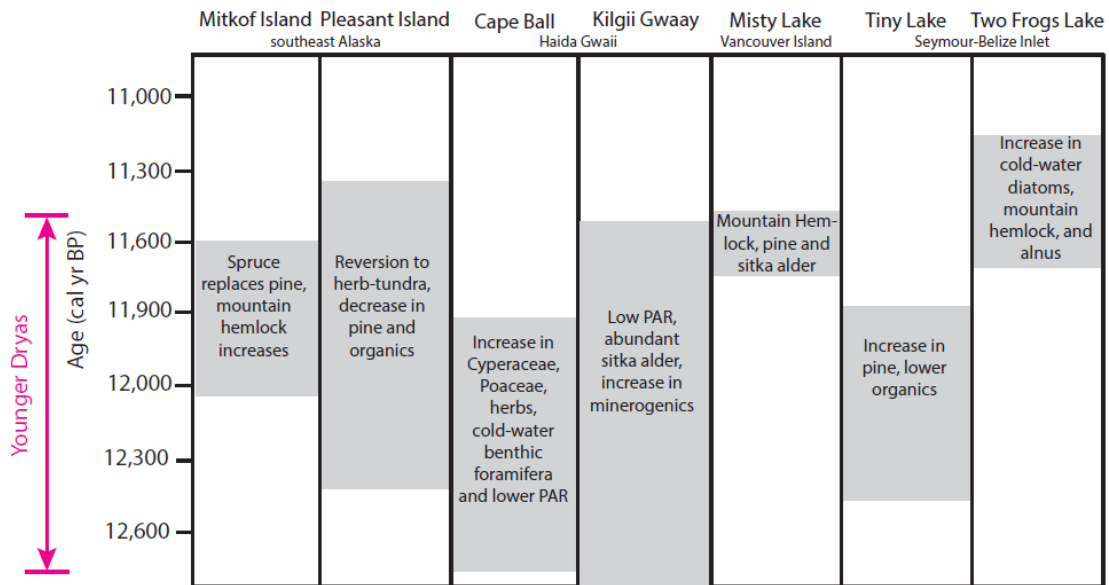


Figure 5.2 Summary of paleoecological signals for Younger Dryas cooling at sites on the Pacific Northwest coast (Ager *et al.* 2010; Hansen and Engstrom 1996; Mathewes *et al.* 1993; Lacourse 2005; Galloway *et al.* 2009; Galloway *et al.* 2007). Boxes indicate period that signals occur and pink arrow indicates duration of the Younger Dryas period.

Mitkof Island is located ~ 260 km southeast of Pleasant Island core from muskeg peat near Petersburg on Mitkof Island was dated and analyzed for pollen (Figure 5.1; Ager *et al.* 2010). A chronology based on 12 AMS radiocarbon dates of peat samples revealed a basal age of 12,884 cal yr BP. The pollen record shows a decrease in *Pinus* during the middle of the Younger Dryas, followed by an increase in *Picea* ~12,200 cal yr BP. *Tsuga mertensiana* also increases from 0 to 17% in this zone. The increase in *Tsuga mertensiana* suggests a cool and wet climate, as discussed by Mathewes (1993). This pattern, although similar to the vegetation change in the Pleasant Island record, does not demonstrate the same increase in herbs and other shrub tundra plants (Ager *et al.* 2010).

Fedje *et al.* (2011) reviewed the pollen record from Cape Ball on eastern Graham Island and Hippa Lake on the west coast, as well as benthic foraminifera from three west coast marine cores (Figure 5.1 and 5.2). All three records exhibit a peak in a benthic cold-water foraminifera (*Cassidulina reniforme*) between ~12,960 to 11,850 cal yr BP (11,070-10,170 ¹⁴C yr BP). Ocean water, and presumably climate cooled during Younger Dryas time and then warmed again around 11,850 cal yr BP (10,170 ¹⁴C yr BP; Mathewes *et al.* 1993). The Cape Ball pollen record begins about 18,640 cal yr BP (15,400 ¹⁴C yr BP). A pollen-climate transfer function was used to generate estimates of precipitation and mean July temperatures. Mean July temperatures decreased 2-3 °C between 12,880 to 11,890- cal yr BP (11,000-10,200 ¹⁴C yr BP), and precipitation. A peak in Poaceae pollen coincides with the cool interval, which is followed by increases in *Picea*, *Tsuga heterophylla* and a decline in herbs in the pollen assemblage (Mathewes *et al.* 1993). The palynology of a second site in Cape Ball shows a decline in *Picea* pollen around 12,640 cal yr BP (10,730 ¹⁴C yr) with increases of Cyperaceae, Poaceae and other herbs, similar to the Pleasant Island record. The zone is also characterized by lower pollen accumulation rates, which Mathewes *et al.* (1993) interpreted as indicative of cooler and wetter conditions. Both records suggest cooling was regional and peaked between 12,640-11,890 cal yr BP (10,730 -10,200 ¹⁴C yr BP).

Two sites from the central coast of B.C. that span the Younger Dryas chonozone are included in the Fedje *et al.* (2011) review (Figure 5.1 and 5.2). Tiny Lake in the Seymour-Belize Inlet area, shows possible evidence for cooling signal Younger Dryas-

aged pollen samples (Galloway *et al.* 2009). The chronology of this record was based on four AMS radiocarbon ages from bulk samples ranging from ~13,602 to 7693 cal yr BP (12,000-6860 ¹⁴C yr BP). Between ~12,650 to 11,820 cal yr BP (10,750-10,150 ¹⁴C yr BP), *Pinus* pollen increased to 30% while *Picea* and *Abies* declined, interpreted as a possible signal of Younger Dryas cooling. An 8% decrease in the organic content of lake sediment was also detected in this zone by LOI, another feature characteristic of Younger Dryas sediment. Galloway *et al.* (2009) suggest that decreased organic matter may indicate increased erosion due to reduced vegetation cover or reduced lake productivity associated with Younger Dryas cooling. Overall, the record shows a transition from *Pinus* parkland during deglaciation to a forest with mesophytic conifers, followed by a temporary reversal ~12,650- 11,820 cal yr BP (10,750-10,150 ¹⁴C yr BP), when cooler and drier conditions favoured *Pinus*, synchronous with the Younger Dryas (Galloway *et al.* 2009).

Misty Lake on northern Vancouver Island also provides evidence for a cooler climate during the Younger Dryas (Figure 5.1 and 5.2; Lacourse 2005). Bulk radiocarbon ages from six sediment samples date the record from 12,210 cal yr BP to present. The Misty lake record shows an increase in *Pinus* and *Tsuga mertensiana* in Younger Dryas-aged sediments, interpreted as indicating cooler temperatures and higher winter precipitation. Increases in the PARs of *Tsuga mertensiana*, *Pinus contorta*, and *Alnus crispa* from 11,660 to 11,480 cal yr BP indicate a return to cooler and moister conditions coincident with the Younger Dryas event (Lacourse 2005).

In addition to the sites reviewed by Fedje *et al.* (2011), other sites on the Pacific Northwest coast show evidence for cooling during the Younger Dryas. Pollen records from other lake cores in the Seymour-Belize Inlet Complex show evidence for Younger Dryas cooling (Figure 5.1 and 5.2; Galloway *et al.* 2007). A paleoecological record from Two Frogs Lake indicates cooling ~11,040 ¹⁴C yr BP (13,030 cal yr BP) based on the occurrence of *Tsuga mertensiana*, persistence of *Alnus*, a decline in a thermophilous diatoms (*Cyclotella stelligera*) and increase in diatoms favouring cooler water (*Fragilaria lata* and *F. Exigua*). The chronology is only based on five bulk radiocarbon ages due to the scarcity of plant macrofossils and *Alnus* is not identified to species level. Similar increases in *Tsuga mertensiana* have been found during this period on northern

Vancouver Island and in records from southern B.C (Hebda 1983; Mathewes 1973; Pellatt *et al* 2002).

Although strong evidence for Younger Dryas cooling has been found at sites such as Cape Ball, other records on the Pacific Northwest coast show little or no such evidence. For example, a record from Hippa Lake, a hypermaritime lake on a small island off the central-west coast of Graham Island, exhibits a weak signal of Younger Dryas cooling (Lacourse *et al.* 2012). Only a faint signal is apparent, with an increase in *Alnus viridis*, herbaceous pollen and Polypodiaceae fern spores, suggestive of limited Younger Dryas cooling. However, only three of the Hippa Lake pollen samples fell within the Younger Dryas chronozone. The cooling signal is contradicted by the presence of mesothermal taxa such as *Alnus rubra* and *Picea stichensis* and high pollen accumulation rates (PAR), suggesting the environment was not substantially cooler than present day (Lacourse *et al.* 2012). These findings are consistent with another hypermaritime site on the west coast of south Moresby Island (West Side Pond), which also exhibits increased PARs during the Younger Dryas, indicating conditions were not significantly cooler than today (Figure 1.1; Lacourse *et al.* 2005).

This summary of postglacial paleoecological sites in the Pacific Northwest draws attention to the need for more robust radiocarbon records and higher sampling resolution in the region. The Younger Dryas chronozone occurred within a short span of time, which requires high sample. Many previous paleoecological studies on the Pacific Northwest coast have poor chronologies based on bulk radiocarbon ages on a few samples, rather than larger numbers of AMS ages on discrete macrofossils. More studies that take a multi-proxy approach to reconstructing climate using pollen, diatoms, foraminifera, chironomids, and other biological indicators may resolve uncertainty surrounding climate conditions during Younger Dryas.

It remains unclear why vegetation response to Younger Dryas differs so much throughout the region, however is likely related to site-specific differences in physical environments. Younger Dryas cooling in the Pacific Northwest was possibly caused by reintensification of anticyclonic circulation from the east that temporarily displaced moist Pacific air. Hansen and Engstrom (1996) suggest paleoecological sites, such as Lily

Lake in southeast Alaska, may be too far inland from the Pacific Ocean for the displacement of moist maritime air to impact vegetation. Alternatively, it has been suggested that the moderating effect of the ocean may cooler temperatures associated with the Younger Dryas in hypermaritime locales (Fedje *et al.* 2011; Lacourse *et al.* 2012). This in part may explain why Kilgii Gwaay and other hypermaritime sites, such as West Side Pond and Pleasant Island show no strong cooling signal (Mann 1983; Hansen and Engstrom 1996; Lacourse *et al.* 2005). Temperature thresholds of individual plant taxa may also explain varying responses to the Younger Dryas, where cooling may not have been dramatic enough to impact the distribution of mesic taxa (Lacourse *et al.* 2012). It is likely that climatic variability in paleoecological records from the Pacific Northwest is the result of a multitude of complex sub-regional factors such as elevation, presence of mountain ranges and glacier conditions (Fedje *et al.* 2011). Lastly, paleoecological records on the Pacific Northwest coast may fail to show strong evidence for Younger Dryas cooling due to poor sampling resolution, low pollen counts, and inadequately dated sites (Hansen and Engstrom 1996; Lacourse *et al.* 2012).

Understanding how past climatic events have impacted vegetation communities is important in predicting and assessing future environmental response to climate warming. Climate modelling that includes both atmosphere and ocean models indicate that increased anthropogenic greenhouse gases could greatly impact thermohaline circulation by causing it to become unstable and cause abrupt cooling, similar to what happened experienced during the Younger Dryas (Broecker 1997; Schlesinger *et al.* 2006). Determining the extent of the impact the Younger Dryas had on a global scale by investigating different regions such as along the Pacific Northwest coast will aid our understanding of how the environment may respond in the future.

Chapter 6. Conclusions

The two main research objectives of this study were to provide a high-resolution reconstruction of vegetation establishment and succession following the last glaciation, and determine if Younger Dryas cooling is detectable in the record. A third objective focuses on the paleoenvironment of the Kilgii Gwaay archaeological site, using sedimentary charcoal in addition to pollen and spores. In order to achieve these objectives, a core was taken from Kilgii Pond on southern Haida Gwaii and analyzed for fossil pollen and spores to reconstruct an early postglacial vegetation record. AMS radiocarbon ages obtained from plant macrofossils were used to construct an age-depth model and constrain the chronology of events.

The high resolution paleoecological study reveals a pattern of postglacial vegetative succession similar to that reported at other sites in the region. The Kilgii Pond record shows the initial establishment of vegetation ~14,510 cal yr BP, with a local vegetation assemblage consisting of herb-shrub tundra with abundant sedges, grasses and other herbaceous taxa. This early treeless landscape transitions into a pine-dominated forest ~14,000 cal yr BP. Pine was largely replaced by spruce ~13,290 cal yr BP and *Tsuga heterophylla* becomes established ~12,420 cal yr BP. Evaluating this record and comparing Kilgii Pond to other regional studies have revealed that climate amelioration following deglaciation was a major factor influencing vegetation establishment and succession. Changing postglacial climate combined with biogenic factors such as adaptations and phytogeography of plant taxa, are the underlying mechanisms for changes in the vegetation assemblages.

In addition to providing a valuable record of vegetation history for the region, the charcoal record from Kilgii Pond provides indirect evidence of early human occupation at the Kilgii Gwaay archaeological site. Charcoal fragments are present in the core from ~11,593 to 10,649 cal yr BP (80-54 cm), which encompasses the known time of early

human occupation of the site (10,700 cal yr BP). The charcoal record also suggests the period of occupation may have begun as early as 11,593 cal yr BP, or ~800 years earlier than previously thought. Early maritime adaptations of humans on the coast indirectly support the argument for early coastal migration of people south from Beringia.

A final major objective of this project was to help reconcile uncertainty regarding the Younger Dryas chronozone and to what extent this event affected the Pacific Northwest region. The paleoecological record from Kilgii Pond exhibits what may be interpreted as a weak signal of Younger Dryas cooling, principally a decreased spruce, increased *Alnus viridis*, low PARs and reduced organic content. The underlying cause for variability in vegetative response to Younger Dryas cooling throughout the Pacific Northwest remains unclear, however it is likely related to differing subregional factors as well as the paucity of records from the early postglacial period. The weak signal at Kilgii Gwaay is likely attributable to the site being near the Pacific Ocean and its resulting moderating effects on the local climate. This study and review of Younger Dryas-aged sites in the Pacific Northwest draw attention to the need for more high-resolution paleoecological studies within the region to better understand how short-term climatic change associated with the Younger Dryas chronozone affected the Pacific Northwest.

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