Postglacial Vegetation History of Hippa Island, Haida Gwaii (Queen Charlotte Islands),
British Columbia, Canada

by

J. Michelle Delepine
B.Sc., Oregon State University, 2006

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of

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Abstract

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Pollen analysis of lake sediments was used to reconstruct the postglacial vegetation history of Hippa Island (53°31'50" N, 132°58'24" W), located on the exposed west coast of Haida Gwaii (Queen Charlotte Islands) on the northern British Columbia coast.

A 3.55 m sediment core was extracted from Hippa Lake, a small, shallow lake on Hippa Island. Five radiocarbon ages were obtained on organic-rich sediment. A linear age-depth model estimated the base of the sediment core to be 14,000 cal yr BP (12,000 ^14C yr BP). Pollen and spores extracted from sediment subsamples (1 cm^3) taken along the length of the core were identified and counted to a minimum sum of 500 pollen and spores, except for four basal samples, which had low pollen concentrations.

Hippa Island’s vegetation history shares broad similarities to other vegetation records from Haida Gwaii and elsewhere along the British Columbia coast; however, climate fluctuations are not well recorded by the predominantly mesic pollen assemblages. The late-glacial period (14,000–13,500 cal yr BP; 12,000–11,400 ^14C yr BP) records a diverse herb-dominated vegetation community composed of Cyperaceae, Artemisia, Salix, and many other herbs. Transition to Pinus woodland by 13,250 cal yr BP (11,250 ^14C yr BP) is followed by increases in Alnus viridis and Alnus rubra, and the
arrival of Picea. A decrease in Pinus and minor increases in ferns and herbs coincide with the Younger Dryas cold period; however, regression to tundra or increased Tsuga mertensiana, which characterized Younger Dryas cooling at other sites along the north Pacific coast, did not occur on Hippa Island. After 11,000 cal yr BP (9750 $^{14}$C yr BP), a sharp change in vegetation occurs with Pinus, Alnus viridis, and Cyperaceae being replaced by Picea, Tsuga heterophylla and Lysichiton americanus. Despite well-documented evidence of a warmer and drier interval during the early Holocene, the composition of the mesic vegetation communities on Hippa Island was relatively stable during this time. Increases in Cupressaceae after 6000 cal yr BP (5300 $^{14}$C yr BP) suggest increasing precipitation in the mid-Holocene. Modern mixed Cupressaceae-Picea-T. heterophylla forest formed by 4500 cal yr BP (4000 $^{14}$C yr BP).
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Dedication

To my loving family and husband.
Chapter 1: Introduction

Introduction

Pollen and spores preserved in lake sediments offer important records of vegetation change through time (Birks and Birks 1980; Fægri and Iversen 1981; Bennett and Willis 2001). In general, only the outer surfaces of pollen, known as the exine, are preserved (Fægri and Iversen 1981; Bennett and Willis 2001). Exine morphology varies between pollen types and this allows pollen grains to be identified to the family or genus level. In some cases, it is also possible to identify pollen grains to the species level.

In addition to lake sediments, pollen is also preserved in peat bogs, forest hollows, marine sediments, and other depositional environments (Fægri and Iversen 1981; Jacobson and Bradshaw 1981; Bennett and Willis 2001). Pollen grains from anemophilous plants (i.e. plants that disperse pollen via wind) are most commonly encountered in sedimentary archives because of the sheer volume of pollen that is produced and scattered across the landscape (Fægri and Iversen 1981). Because pollen dispersal is typically an annual event and because pollen tends to be well preserved in anaerobic sediments, lake sediments contain strata of fossil pollen in time sequence (Birks and Birks 1980; Fægri and Iversen 1981; Bennett and Willis 2001). Pollen grains isolated physically and chemically from the associated sediment matrix can be identified with light microscopy and recorded in respect to the time sequence in which they are found (Birks and Birks 1980; Fægri and Iversen 1981; Bennett and Willis 2001; Berglund and Ralska-Jaziewiczowa 2003). For the most part, the proportions of pollen types found in each sediment sample vary in relation to the amount of its parent vegetation, and hence
pollen percentages are assumed to represent the composition of vegetation around a site (Birks and Birks 1980; Bennett and Willis 2001). The representative area of a particular pollen record depends on a number of factors, but both models (e.g. Jacobson and Bradshaw 1981) and empirical studies (Bradshaw and Webb 1985) suggest that the size of the pollen source area is related primarily to the size of the basin from which the pollen record is collected, with small depressions, such as forest hollows, capturing mostly local pollen and larger basins, such as lakes accumulating both local and regional pollen.

Interpreting fossil pollen data requires a multi-disciplinary approach, as there are several potential drivers of vegetation change (Bennett and Willis 2001). These may include changes in climate, ecological factors, and human activity. Estimates of paleoclimatic conditions from foraminifera or chironomid analyses, or from ice cores, can be used to provide support for climate-induced vegetation change and distinguish these from other factors (Birks 2003). Comparing pollen records from several sites can reveal vegetation patterns at local and regional scales (Birks and Birks 1980; Fægri and Iversen 1981; Jacobson and Bradshaw 1981).

**Research Objectives**

The overall goal of the research was to determine Holocene vegetation change on Hippa Island (Figure 1), a small island on the west coast of Haida Gwaii (Queen Charlotte Islands), along British Columbia’s north Pacific coast. Fossil pollen and spores extracted from lake sediments collected by Walker and Mathewes (1988) were used to reconstruct the vegetation history of Hippa Island. The results are compared to other vegetation reconstructions from Haida Gwaii (e.g. Mathewes and Clague 1982;
Figure 1. Map of Haida Gwaii showing the location of Hippa Island, and other paleoecological study sites mentioned in the text.
Warner et al. 1982; Warner 1984; Quickfall 1987; Fedje 1993; Heusser 1995; Pellatt and Mathewes 1994, 1997; Lacourse et al. 2003, 2005; Lacourse 2004; Lacourse and Mathewes 2005; Hebda et al. 2005) and adjacent areas (e.g. Heusser 1985; Lacourse 2005; Hansen and Engstrom 1996) for the purpose of identifying regional pollen signals. Vegetation reconstructions are also compared to independent paleoclimatic data (Mathewes and Heusser 1981; Heusser et al. 1985; Heusser 1985; COHMAP 1988; Koerner and Fisher 1990; Bartlein et al. 1998; Kienast and McKay 2001) in order to identify climate-induced vegetation change. These comparisons highlight both similarities and differences between vegetation and climate at Hippa Island and those found at other sites on British Columbia’s coast.

**Significance**

The Hippa Lake vegetation record contributes to a growing body of paleoecological research from the north Pacific coast. Because pollen records are a function of both locally and regionally-derived pollen, new pollen studies result in a greater understanding of local and regional vegetation dynamics and species migrations. In addition, vegetation records provide historical perspective on the origin of coastal rainforest development. Given that the dominant species of coastal rainforests live to be several hundred years old, records of vegetation change are needed to investigate questions regarding succession and long-term vegetation dynamics. Furthermore, the resilience of vegetation communities to climate change can be studied when vegetation histories are compared with paleoclimate records.
Regional Setting

Paleoenvironmental History

Haida Gwaii is an archipelago comprised of about 150 islands (Figure 1), approximately 80 km offshore from the Pacific coast of mainland British Columbia. Hecate Strait separates the island group from the mainland. Three distinctive physiographic units reflect the islands topography: the Queen Charlotte Ranges, the Skidegate Plateau, and the Queen Charlotte Lowlands (Sutherland-Brown and Yorath 1989).

The late Quaternary glacial history of Haida Gwaii is well-documented, but uncertainties regarding possible ice-free areas remain. During the most recent period of glaciation beginning approximately 35,000–30,000 cal yr BP (30,000–25,000 $^{14}$C yr BP) (Clague 1977, 1981; Warner et al. 1984), ice caps originating from the Queen Charlotte Ranges developed slowly and independently of the Cordilleran Ice Sheet on the British Columbia mainland (Clague et al. 1982; Clague 1983) and it is possible that low-lying areas were only briefly glaciated or even remained unglaciated (Clague 1989). Maximum glacial extent occurred after 25,000 cal yr BP (21,000 $^{14}$C yr BP). The only noted location of coalescence between ice from Haida Gwaii and that from the British Columbia mainland is along the north-east coast of Graham Island (Blaise et al. 1990) and in Dixon Entrance (Sutherland-Brown 1968; Hicock and Fuller 1995; Clague 1989; Barrie and Conway 1999). This coalescence may have been short-lived (Clague 1989) with glacial retreat from Dixon Entrance beginning between 19,000–14,000 cal yr BP (16,000–12,500 $^{14}$C yr BP) (Barrie and Conway 1999; Hetherington et al. 2004) and in Hecate Strait by 17,370 cal yr BP (14,330 $^{14}$C yr BP) (Lacourse et al. 2005). By 18,500 cal yr BP (15,000 $^{14}$C yr BP), during a time when Wisconsin ice elsewhere was at its maximum, a glacial
retreat began on the eastern shore of Graham Island that allowed for the propagation of vegetation prior to extensive deglaciation (Warner et al. 1982; Mathewes et al. 1985; Mathewes 1989; Lacourse et al. 2005).

Substantial changes in sea level occurred on the coast of British Columbia at the end of the last glaciation as a result of a complex interplay of changes in climate, glacial loading/unloading and tectonics (Clague 1985; Josenhans et al. 1997; Hetherington et al. 2004). Even with eustatic sea level rise, relative sea level in Haida Gwaii region was 150 m below present at the end of the last glaciation (Josenhans et al. 1997; Fedje and Josenhans 2000; Hetherington et al. 2004). During periods of minimum relative sea level, portions of the continental shelf between Haida Gwaii and the mainland were exposed, ice-free, and vegetated (Josenhans et al. 1997; Fedje and Josenhans 2000; Lacourse et al. 2003, 2005; Hetherington et al. 2004). As continental ice sheets melted, sea level rose, reaching modern levels around 10,500 cal yr BP (9400 $^{14}$C yr BP) (Fedje and Josenhans 2000).

The climate of the late-glacial period was cool and a predominance of dry, easterly wind may have decreased precipitation (Mathewes and Heusser 1981; Heusser 1985; Heusser et al. 1985; COHMAP 1988; Bartlein et al. 1998; Kienast and McKay 2001). An acute global cooling event known as the Younger Dryas briefly reduced temperature on the north Pacific coast between 12,500 and 11,600 cal yr BP (10,700 and 10,000 $^{14}$C yr BP) (Mangerud et al. 1974; COHMAP 1988; Mathewes 1993; Mathewes et al. 1993; Bartlein et al. 1998; Björck et al. 1998; Kienast and McKay 2001). The transition from the Pleistocene to the Holocene ca. 11,500 cal yr BP (ca. 10,000 $^{14}$C yr BP) is marked by the onset of warmer and drier conditions than those of present-day
(Mathewes and Heusser 1981, 1985; Heusser et al. 1985; COHMAP 1988; Koerner and Fisher 1990; Bartlein et al. 1998; Kienast and McKay 2001). The early Holocene warm, dry period ca. 11,500–8000 cal yr BP (ca. 10,000–7000 \(^{14}\)C yr BP) gave way to increasing precipitation and cooling and modern cool, moist climate regimes were established by the late Holocene (Heusser 1985; Heusser et al. 1985; Pellatt and Mathewes 1994, 1997) approximately 3000–4500 cal yr BP (3000–4000 \(^{14}\)C yr BP).

**Refugia**

Possible ice-free areas that may have supported refugia have been identified at a number of sites along the north Pacific coast, including on Vancouver Island on Brooks Peninsula (Pojar 1980; Hebda 1997), in southeastern Alaska in the Alexander Archipelago (Heusser 1954; Harris 1965; Worley and Jacques 1973), in the Gulf of Alaska (Heusser 1989), and in southwestern Alaska on Kodiak Island (Karlstrom and Ball 1969; Heusser 1971). A continuous ice-free refugium spanning the Wisconsin glaciation has yet to be found on Haida Gwaii (Heusser 1989), but geologic evidence for ice-free areas available for plant habitation include the subaerially exposed shelf of Hectate Strait (Clague et al. 1982; Hetherington et al. 2003), isolated nunataks of the Queen Charlotte Ranges (Sutherland-Brown and Nasmith 1962; Clague et al. 1982; Clague 1989), and the west coast of Graham or Moresby Island (Clague et al. 1982; Hetherington et al. 2004). Vegetation on Haida Gwaii is recorded from 49,000–31,500 cal yr BP (45,700–27,500 \(^{14}\)C yr BP) and again beginning 18,500 cal yr BP (15,000 \(^{14}\)C yr BP) (Warner et al. 1984; Mathewes et al. 1985), but evidence of ice-free, vegetated areas between these periods has not yet been discovered. The diversity of vegetation recorded at the Cape Ball seacliffs on eastern Graham Island (Figure 1) at 18,500 cal yr
BP (15,000 $^{14}$C yr BP), while glacial ice was at its maximum on the mainland of British Columbia (Clague 1981; Hetherington et al. 2004), suggest that nearby refugia may have existed (Warner et al. 1982). A chironomid study on Hippa Lake sediment found that Corynocera rapidly colonized the lake beginning 13,980 cal yr BP (11,760 $^{14}$C yr BP) despite their incapacity to fly, a finding which may be explained by nearby refugia (Walker and Mathewes 1988). The refugium hypothesis also explains the prevalence of numerous endemic species or subspecies on Haida Gwaii, including plants (Calder and Taylor 1968), mosses (Schofield 1989), beetles (Kavanaugh 1992), fish (Moodie and Reimchen 1973), birds, and mammals (Foster 1965; Cowan 1989; Byun et al. 1997).

**Modern Vegetation and Climate**

Lowland forests on Haida Gwaii are generally dominated by *Tsuga heterophylla*, *Thuja plicata*, and *Picea sitchensis* (Calder and Taylor 1968). These forests are part of the Coastal Western Hemlock Biogeoclimatic Ecosystem Classification Zone (CWH), which flanks the coastal region of British Columbia covering much of Haida Gwaii, Vancouver Island, and the Coast Mountains of the British Columbia mainland (Pojar et al. 1991; Banner et al. 1993). This ecosystem type extends northward into Alaska and south down the coast through Washington and Oregon (Pojar et al. 1991). Generally, this zone is constrained to lower elevations on the windward side of coastal mountain ranges, from sea level to approximately 1000 m, depending on latitude and topographically-induced rain shadows (Pojar et al. 1991).

Vegetation characteristics in the CWH zone are notably marked by the dominance of *Tsuga heterophylla*, a poorly developed herb layer, and the prevalence of various moss (e.g. *Hylocomium splendens*, *Rhytidiadelphus loreus*) and fern (e.g. *Athyrium felix-*)
femina, Pteridium aquilinium, Polystichum munitum) species (Pojar et al. 1991). Abies amabilis is locally abundant in portions of the CWH zone; however, native Abies populations are now absent from Haida Gwaii archipelago (Calder and Taylor 1968). Both Tsuga heterophylla and Picea sitchensis are found on sites ranging from relatively dry to wet, both in lowlands and uplands; however, P. sitchensis is less shade tolerant than T. heterophylla (Calder and Taylor 1968; Klinka et al. 1989; Medinger and Pojar 1991; Pojar and Mackinnon 1994). Thuja plicata is also shade tolerant and usually occupies moist to wet sites. Alnus rubra grows in moist, disturbed areas such as floodplains. In addition to these, Pinus contorta var. contorta can also be found at extremely wet or dry sites. Wet sites are also typically associated with Lysichiton americanus.

Areas along the outer Pacific Coast, including the west coast of Haida Gwaii, are further delineated into hypermaritime subzones of the CWH zone (Pojar et al. 1991). These subzones are characterized by a prevalence of bogs and wetlands (Banner et al. 1993). Blanket bogs are most common in lowlying areas along the outer coast, where peat accumulation can be several metres thick. Scrub Pinus contorta var. contorta and Thuja plicata are common, albeit scattered, features of bog woodlands. Cyperaceae sedges and Salix species are common vegetation components in non-forested wetlands (Banner et al. 1993).

The occurrence of bogs within the CWHvh is a signature of the area’s high precipitation, cool summers, and mild winters. A long-term weather station at Langara Island (Figure 1), approximately 80 km north of Hippa Island, records a mean annual temperature of 7.7°C and a mean annual precipitation of 1957 mm/yr (Canadian Climate
Normals 1971–2000). Due to high precipitation rates, the already nutrient poor soil is susceptible to further nutrient loss through leaching (Pojar et al. 1991).

**Study Site: Hippa Island**

Hippa Island is one of few islands west of Graham Island in Haida Gwaii archipelago (Figure 1) and lies within the Vladimir J. Krajina Ecological Reserve. The island is small (5 km$^2$) and located 0.7 km offshore, in an area of open Pacific Ocean exposure. The island is underlain by Tertiary basalt and rhyolite from the Masset Formation (Sutherland-Brown 1968) and reaches a maximum elevation of 450 m. Hippa Lake (53°31'50” N, 132°58'24” W, 230 m asl) is small (3.2 ha) and shallow (1.1 m) (Figure 2), with a 0.4 km$^2$ catchment basin (Walker and Mathewes 1988); no inflowing stream is currently present. *Nuphar lutea* is abundant in Hippa Lake. The vegetation surrounding the lake is dominated by *Thuja plicata*, *Picea sitchensis*, and *Tsuga heterophylla*, but also includes *Alnus* and *Pinus contorta*.

![Figure 2. Hippa Lake looking east to Hippa Island's 450 m peak. (Photograph courtesy of R.W. Mathewes.)](image)
Previous Paleoecological Studies on Haida Gwaii

Fossil pollen and plant macrofossil analyses have been conducted at a number of sites on Haida Gwaii (Figure 1). The late-glacial and mid- to late Holocene periods are best represented by these vegetation records. Fewer studies have resulted in continuous vegetation reconstructions that span the late-glacial period to the present.

Warner et al. (1984) present pollen and plant macrofossil evidence from a peat bed at Pilot Mill (Figure 1) that spans 49,000–31,500 cal yr BP (45,700–27,500 $^{14}$C yr BP), which is substantially older than other pollen records from the region. The Pilot Mill reconstruction is the first documented mid-Wisconsin vegetation record on the north coast of British Columbia. The vegetation reconstruction records herb tundra giving way to a mix of Picea-Tsuga mertensiana forest and open wetlands at 49,000 cal yr BP (45,700 $^{14}$C yr BP); a bog complex develops near the record’s end (Warner et al. 1984). This study also highlights the mid-Wisconsin presence of Abies, now extinct from Haida Gwaii.

The earliest record of post-glacial vegetation communities on the north coast of British Columbia is found at the Cape Ball seacliffs (Figure 1), on the east side of Graham Island (Warner et al. 1982; Warner 1984). This diverse, tundra-like vegetation record begins around 18,000 cal yr BP (15,000 $^{14}$C yr BP) (Mathewes et al. 1985), which suggests that ice-free, vegetated terrain existed exceptionally early on eastern Graham Island compared to mainland British Columbia (Clague 1981; Hetherington et al. 2004). Cape Ball vegetation reconstructions indicate that diverse herb and shrub tundra dominated the late-glacial landscape prior to Pinus colonization (Mathewes and Clague 1982; Warner et al. 1982; Warner 1984). These studies also found fossil pollen evidence of Polemonium caeruleum, a northern, subalpine herb that no longer exists on Haida
Gwaii (Calder and Taylor 1968). Sediments at the Cape Ball seaciffs are subsequently overlain by marine deposits. Pollen and plant macrofossils from Cape Ball are also used to describe late-glacial vegetation history in Mathewes and Clague (1982).

Vegetation history is reconstructed using fossil pollen and plant macrofossils from the emergent continental shelf in Hectate Strait at three sites: Dogfish Bank (Lacourse et al. 2005), Logan Inlet (Lacourse 2004; Lacourse and Mathewes 2005), and Juan Perez Sound (Fedje and Josenhans 2000; Lacourse et al. 2003) (Figure 1). These studies confirm that portions of Hectate Strait were subaerially exposed and vegetated during the late-glacial period. Herb and shrub tundra characterize the vegetation history at Dogfish Bank prior to 15,000 cal yr BP (13,000 \(^{14}\)C yr BP) (Lacourse et al. 2005), while records from Logan Inlet (Lacourse 2004; Lacourse and Mathewes 2005) and Juan Perez Sound (Fedje and Josenhans 2000; Lacourse et al. 2003) occur after 14,000 cal yr BP (12,000 \(^{14}\)C yr BP) during a period of abundant \(\textit{Pinus}\) and Polypodiaceae ferns.

Fedje (1993) reconstructed post-glacial vegetation history for West Side Pond (Figure 1), a hypermaritime site on the west coast of Moresby Island. The late-glacial portion of this record was subjected to higher-resolution pollen analyses, increased dating control, and the analysis of conifer stomata microfossils by Lacourse et al. (2005). Late-glacial vegetation at this site is characterized by a succession of herb tundra, dwarf shrub tundra, and \(\textit{Pinus}\) woodlands. \(\textit{Pinus}\) stomata confirm its presence by 15,600 cal yr BP (13,000 \(^{14}\)C yr BP), which is earlier than other sites on Haida Gwaii. Sustained \(\textit{Alnus}\) percentages and fluctuations in \(\textit{Tsuga heterophylla}\) suggest warm, dry conditions in the early Holocene; mixed \(\textit{T. heterophylla-Picea-Pinus}\) forest include Cupressaceae after 4500 cal yr BP (4000 \(^{14}\)C yr BP).
SGang gwaay (Anthony Island), another hypermaritime site, is located off the southern tip of Moresby Island. Using pollen and plant macrofossil analyses, Hebda et al. (2005) reconstructed a 14,000 cal yr BP (12,500 $^{14}$C yr BP) record of vegetation history from sediments deposited in a forest hollow. A late-glacial *Pinus* period is followed by *Picea* dominance; the expansion of *Tsuga heterophylla* is delayed. Subsequent mixed *Picea-T. heterophylla* forest characterizes the majority of the mid- to late Holocene record. Given the likely limited origin of pollen, this study focuses on aspects of local vegetation dynamics.

Pellatt and Mathewes (1994, 1997) conducted pollen and plant macrofossil analyses on lake sediment cores from three high elevation sites i.e., Louise Pond, Shangri-La Bog, and SC-1 Pond (Figure 1) on Haida Gwaii. These studies found that treeline increased amid a warm, dry early Holocene, as evidenced by the presence of *Tsuga heterophylla* macrofossils. A lowering of the treeline and the formation of Shangri-La Bog and SC-1 Pond suggest regional cooling by 8000 cal yr BP (7000 $^{14}$C yr BP). Increases in Poaceae and *T. mertensiana* during the late Holocene suggest that vegetation became increasingly open and subalpine beginning at a time of glacial advance (i.e., 3600 cal yr BP, 3400 $^{14}$C yr BP) on the British Columbia mainland.

Several bogs at the Queen Charlotte Lowlands on northeastern Graham Island and one on Kunghit Island on the southern end of Haida Gwaii were the subject of vegetation reconstructions by Warner (1984) and Quickfall (1987). Vegetation records using pollen and plant macrofossils from Boulton Lake and Serendipity Bog (Figure 1) (Warner 1984) are characterized by the development of *Picea-Tsuga heterophylla* forest during the early Holocene and by the arrival of Cupressaceae and the development of peatlands during the
late Holocene. Quickfall (1987) also found pollen and macrofossil evidence at Argonaut Hill Bog, Drizzle Pit Bog, and Kunghit Island Bog (Figure 1) to suggest that regional paludification began around 5500 cal yr BP (5000 $^{14}$C yr BP).

Many of these vegetation trends are also inferred from a reconstruction at Langara Island (Figure 1) (Heusser 1995); however, the Langara Island study is not independently-dated, but rather its chronology is based on stratigraphic correlation to Warner et al. (1982), Mathewes and Clague (1982), Warner (1984), and Mathewes (1989). Similar trends in vegetation change are also noted in older studies by Heusser (1955, 1960) that lack chronological control.

A biometric study on fossil and modern Picea cones by Warner and Chmielewski (1987) suggest that a hybrid of P. glauca and P. sitchensis occurred during the late-glacial period at Cape Ball. Accordingly, Picea pollen, stomata, and macrofossils in paleoecological records from Haida Gwaii may not be solely derived from P. sitchensis despite the fact that it is the only native Picea that occurs on Haida Gwaii today (Calder and Taylor 1968).

The sediments used in this study to reconstruct vegetation history on Hippa Island were also the subject of a chironomid study by Walker and Mathewes (1988). The fossil chironomid record suggests a cool late-glacial period, as indicated by the presence of Heterotrissocladius, as well as alpine-restricted genera, Microtendipes and Dicrotendipes; however, chironomid fauna did not change markedly through the Holocene. This may at least in part be explained by the record’s lack of profundal fauna, which are more sensitive to changes in climate than are the littoral fauna common to Hippa Lake (Warner and Mathewes 1988).
Core collection, Sediment Stratigraphy, and Loss-on-ignition Analysis

In 1983, Rolf W. Mathewes and Barry G. Warner used a Livingstone piston corer to collect a lake sediment core 3.55 m in length from a *Nuphar lutea* bed in the centre of Hippa Lake from a water depth of 1.1 m (Walker and Mathewes 1988) (Figure 3A). An impenetrable layer, possibly glacial till, was encountered below basal sediments. The uppermost sediments were collected with a Brown piston corer. Sediment cores were split in the field and the fresh surfaces described and stratigraphy documented by Walker (1988). The core was divided into 5 cm sections from 0–340 cm and into 2 cm sections 347–355 cm, sealed separately in plastic bags, and transported back to Simon Fraser University (Figure 3B), where they were stored at 4°C. Subsamples for loss-on-ignition analysis were weighed before and after ignition at 550°C (Walker and Mathewes 1988) to estimate organic matter content (Dean 1974).

Figure 3. A) Barry G. Warner with sediment samples at Hippa Lake. B) Transporting field equipment from Hippa Lake. (Photographs courtesy of R.W. Mathewes.)
Radiocarbon Dating and Age-Depth Modeling

To develop a chronology for the Hippa Lake sediment core, five conventional radiocarbon ages (Table 1) were obtained on bulk sediment (Walker and Mathewes 1988). The radiocarbon ages ($^{14}$C yr BP) were calibrated to calendar years (cal yr BP) using CALIB 5.0 software (Stuiver and Reimer 1993) and calendar ages were assigned using the weighted average of the associated probability distribution. An age-depth model was constructed using the five calibrated ages as well as the assumed age of -33 cal yr BP for the surface sediment. Before present is defined as 1950; the sediment core was retrieved in 1983, 33 years after 0 cal yr BP. These ages were fitted using linear interpolation and a four-term polynomial curve.

Pollen Analysis

Subsamples (1 cm$^3$) for pollen analysis were taken at 5 cm intervals from 0—340 cm and at 2 cm intervals for 347–355 cm. Preparation of sediments for pollen analysis followed standard methods (Berglund and Ralska-Jasiewiczowa 1986; Fægri and Iverson 1989; Bennett and Willis 2001): each subsample was treated with 10% HCl, 10% KOH, HF, and acetolysis in order to concentrate the fossil pollen and remove other organics, carbonates, and silicates. Two tablets containing 16,180 ± 1460 Eucalyptus pollen grains (Batch #903722) were added to sediment subsamples prior to chemical treatment and served as marker grains in order to calculate pollen concentrations (grains/cm$^3$). The resulting residue was dehydrated with ethanol and mounted on slides with silicone oil, a somewhat viscous medium that allows grains to be rotated to view key identification features and which does not distort or degrade grains (Andersen 1960; Bennett and Willis 2001).
Slides were placed under a bright-field microscope using 400× magnification (with 630× and 1000× magnification used for some determinations), and pollen was identified with the highest taxonomic resolution possible. A modern pollen and spore reference collection at the University of Victoria and published identification keys (e.g. McAndrews et al. 1973; Fægri and Iversen 1989; Kapp et al. 2000) were used to verify identifications. Unpublished keys by R.W. Mathewes and R.J. Hebda, specific to the Pacific Northwest, were used as additional identification aids. Cupressaceae pollen is assumed to be largely derived from *Thuja plicata* with lesser amounts from *Chamaecyparis nootkatensis*, although their pollen is indistinguishable. *Alnus viridis* and *A. rubra* (similar to *A. rugosa*) pollen were differentiated according to Richard (1970), Mayle et al. (1993), and Kapp et al. (2000). Apiaceae pollen types were assigned according to Hebda (1985). Conifer stomata encountered during the course of pollen counting were enumerated, but were not identified to species. In cases where the epidermal tissue was intact, each stoma was counted separately. Botanical nomenclature follows Calder and Taylor (1968) and Flora of North America Editorial Committee (1993+).

With the exception of the lowermost basal levels, which had low pollen concentrations, pollen was identified and counted to a minimum base sum of 500 terrestrial pollen and spores for each subsample. Studies by Maher (1972) and Birks and Birks (1980) show that pollen sums under 500 grains can lead to large statistical errors. Pollen sums for non-basal levels range from 500 to 872.5 grains and spores per sample. *Sphagnum* spores and pollen from obligate aquatic taxa (e.g. *Nuphar luteum*, *Potamogeton* spp., *Isoëtes*) were not including in the main pollen sum. Basal subsamples...
(i.e. 348, 350, 352, and 354 cm) were counted in their entirety with pollen sums for these levels ranging from 157 to 362 grains and spores per sample.

Pollen diagrams were plotted using Tilia 2.0 (Grimm 1993). Pollen accumulation rates (grains/cm$^2$/cal yr), which can be used as an index of vegetation density (Fægri and Iversen 1989, Bennett and Willis 2001), are not presented because of large variations in sediment accumulation rates. Pollen concentrations are referred to when percentage data deviates from pollen concentration trends. Stratigraphically-constrained cluster analysis (CONISS) was used to identify zones of similar pollen and spores assemblages. All taxa that appeared at least once in the record with proportions greater than 2% were included in the cluster analysis.
Chapter 3: Results

Sediment Stratigraphy and Loss-on-ignition Analysis

Basal sediment from 347–355 cm consisted predominately of grey, pebbly clay and had low organic matter content (i.e. ≤5% loss-on-ignition) (Walker and Mathewes 1988), likely an artefact of late-glacial, inorganic outwash. Sediment between 320–347 cm was composed of light-tan gyttja and the remaining 320 cm of sediment consisted of coarse brown detritus gyttja with 20–30% loss by weight after ignition (Walker and Mathewes 1988).

Radiocarbon Dating and Calibration

Radiocarbon ages of five bulk sediment samples and the results of calibration to calendar years are summarized in Table 1. The results suggest that sedimentation rates were especially high between 172.5–262.5 cm, with a period of just under 240 cal yr (260 \(^{14}\)C yr) in which nearly a metre of sediment was deposited (Tables 1 and 2). By comparison, the previous 60 cm were deposited over a period of 3300 cal yr (2760 \(^{14}\)C yr). While it is possible that sediment accumulation increased dramatically during this time, it is likely that one of the two \(^{14}\)C ages bracketing this interval is a poor estimate of the true age of the sediment.
Table 1. Radiocarbon and calibrated calendar ages of sediments from Hippa Lake, British Columbia.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Material</th>
<th>Laboratory Reference Number</th>
<th>Radiocarbon Age* ($^{14}$C yr BP)</th>
<th>Calibrated Age (cal yr BP)</th>
<th>Calendar Age Range (cal yr BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80–85</td>
<td>Coarse detritus gyttja</td>
<td>BETA-16579</td>
<td>4860 ± 140</td>
<td>5589</td>
<td>4820–6290</td>
</tr>
<tr>
<td>170–175</td>
<td>Coarse detritus gyttja</td>
<td>BETA-16580</td>
<td>6760 ± 130</td>
<td>7628</td>
<td>7010–8180</td>
</tr>
<tr>
<td>260–265</td>
<td>Coarse detritus gyttja</td>
<td>BETA-16581</td>
<td>7020 ± 250</td>
<td>7868</td>
<td>6730–9020</td>
</tr>
<tr>
<td>320–325</td>
<td>Gyttja</td>
<td>GSC-3773</td>
<td>9780 ± 110</td>
<td>11,164</td>
<td>10,440–12,070</td>
</tr>
</tbody>
</table>

*BETA dates were reported with an error of $1\sigma$; GSC dates were reported with an error of $2\sigma$.

Table 2. Sedimentation rates of Hippa Lake sediments based on calendar year ages.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Sedimentation Rate (cm/cal yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–82.5</td>
<td>0.015</td>
</tr>
<tr>
<td>82.5–172.5</td>
<td>0.044</td>
</tr>
<tr>
<td>172.5–262.5</td>
<td>0.375</td>
</tr>
<tr>
<td>262.5–322.5</td>
<td>0.018</td>
</tr>
<tr>
<td>322.5–343.5</td>
<td>0.011</td>
</tr>
<tr>
<td>343.5–355</td>
<td>0.011*</td>
</tr>
</tbody>
</table>

*Sedimentation rate is extrapolated from 325–347 cm data.

Age-Depth Model

The linear interpolation and four-term polynomial age-depth models (Figures 2 and 3) returned similar age estimates. The main differences between these models were
1) predicted age for the maximum depth of the core; and, 2) overall smoothness, especially just before and after a known age. The linear model predicted the age at maximum depth to be 13,980 cal yr BP (11,760 $^{14}$C yr BP), whereas the four-term polynomial predicted this age to be 14,570 cal yr BP (12,320 $^{14}$C yr BP). An age-depth model based on linear interpolation was ultimately selected for the chronology because it is the most conservative estimate of the age of these sediments. The sedimentation rate between the radiocarbon ages at 322.5 and 343.5 cm was used to extrapolate ages for basal depths (i.e. 348, 350, 352, and 354 cm).

Figure 4. Age-depth model for the Hippa Lake sediment core based on linear interpolation between calendar ages (Table 1). Error bars reflect calendar age ranges. Chronology is based on this model.
Figure 5. Age-depth model for the Hippa Lake sediment core based on a 4-term polynomial. Error bars reflect calendar age ranges.

Pollen Analysis
Four distinct pollen assemblage zones were derived using the grouping results of stratigraphically-constrained cluster analysis (CONISS) (Figure 6). In general, pollen concentration data (Figure 7) substantiates pollen percentage trends, with a few notable exceptions. Despite these, pollen percentages and pollen concentrations show similar trends overall and concentrations are referred to only when they contrast with percentage results.
Zone HL-1: 354–347 cm; 13,980–13,350 cal yr BP (11,760–11,320 $^{14}$C yr BP)

Basal sediments contain a diverse herbaceous assemblage dominated by Cyperaceae, *Artemisia*, and *Salix*, which reach their maximum values of 47, 26, and 15%, respectively, for the period of record (Figure 8). Total herbaceous pollen values are high (66–84 %); however, *Pinus contorta* type, *Picea*, *Tsuga heterophylla*, and *T. mertensiana* pollen are also present (Figure 9) in small amounts (i.e., less than 5%). Additional herbs include Poaceae, Asteraceae (Tubuliflorae), Apiaceae (e.g. *Angelica* type, *Ligusticum*, *Heracleum*, *Conioselinum* type, *Oenanthe*, *Osmorhiza*), Chenopodiaceae, *Valeriana sitchensis*, *Stellaria* type, *Polemonium pulcherrimum*, *Campanula* type, and *Pinguicula*. Spores in this zone include undifferentiated Polypodiaceae, *Polypodium*, *Lycopodium*, *Equisetum*, *Cryptogramma*, and *Botrychium* (Figure 10). In general, pollen and spore concentrations are very low (1,600–4,100 grains/cm$^3$) in these mineral-rich, clay sediments. Sediment in this zone is characterized as grey pebbly, clay (Walker 1988).

Although a quantitative comparison between the Hippa Lake pollen assemblage and modern pollen assemblages from the north Pacific coast was not made, there are similarities between the HL-1 record and many modern pollen assemblages along the southern coast of Alaska. The closest analog is from Icy Cape in the Aleutian Islands of Alaska (Heusser 1985). The herb and shrub tundra at this site is dominated by Cyperaceae; Poaceae, *Empetrum*-Ericaceae, *Salix*, *Alnus*, Apiaceae, and Asteraceae are also present.
Figure 6. Selected pollen and spore percentages for Hippa Lake, with 10× exaggeration applied to infrequent taxa. Total pollen concentration, CONISS groupings, and zonation are also displayed.
Figure 7. Pollen concentrations of selected taxa for Hippa Lake. Note the differences in scale.
Figure 8. Pollen percentages of selected herb taxa for Hippa Lake, with 10× exaggeration applied to infrequent taxa. Aquatic taxa percentages are also displayed.
Figure 9. Pollen percentages of tree and shrub taxa for Hippa Lake, with 10x exaggeration applied to infrequent taxa.
Figure 10. Spore percentages of fern and fern allies for Hippa Lake, with 10× exaggeration applied to infrequent taxa. Sphagnum percentages are also shown.
Zone HL-2: 347–320 cm; 13,350–11,030 cal yr BP (11,320–9670 \(^{14}\)C yr BP)

An increase in *Pinus contorta* type pollen of up to 35% (maximum for the period of record) characterizes the beginning of this zone (Figure 9). This correlates with an increase in *Alnus viridis* type, which is then followed by an increase in *A. rubra* type. *Picea* pollen increases at 12,500 cal yr BP (10,700 \(^{14}\)C yr BP). A decrease in *P. contorta* type and increases in herb pollen (Figure 8) and Polypodiaceae spores (Figure 10) are noted between 12,500 and 11,600 cal yr BP (10,700–10,000 \(^{14}\)C yr BP). Herbaceous pollen concentrations (Figure 7) exceed 81,000 grains/cm\(^3\), the maximum for the period of record, at 12,500 cal yr BP (10,700 \(^{14}\)C yr BP). *Valeriana sitchensis*, a submontane herb, is present in this zone, as are the first significant amounts of *Isoëtes* (Figure 8). *Athyrium felix-femina* is most abundant in this zone. Pollen and spore concentrations range from 111,000–409,000 grains/cm\(^3\). Perhaps due to the increase in *Pinus contorta* type pollen, pollen percentage data limits the expression of a pronounced peak in *A. viridis* pollen concentrations during initial establishment. Also, the increase in herbs around 12,500 cal yr BP (10,700 \(^{14}\)C yr BP) is more pronounced in the pollen concentration data. Zone HL-2 directly corresponds to a unit of light-tan gyttja in the sediment stratigraphy record (Walker 1988). The diverse late-glacial assemblage in Zone HL-2 likely has no modern analog; however, the abundance of *Pinus* and *Alnus* and the presence of herbs and *Picea* share similarities to a modern *Pinus-Alnus* pollen assemblage at Waldport on the Oregon Coast (Heusser 1985). The abundance of *Pinus* and *Picea* is also found in several modern pollen assemblages from the Montane Spruce and Engelmann Spruce – Subalpine Fir zones of the British Columbia interior, but these sites record *Abies* and relatively little *Alnus* (Hebda and Allen 1993; Pellatt et al. 1997).
Zone HL-3: 320–65 cm; 11,030–4390 cal yr BP (9670–3820 $^{14}$C yr BP)

A sharp change in pollen and spore assemblages occurs at the boundary of zones HL-2/HL-3, with Pinus contorta type, Alnus viridis, and Cyperaceae giving way to Picea, Tsuga heterophylla, Lysichiton americanus, and Polypodium (Figure 6). Picea and Polypodiaceae are dominant throughout this zone, but gradually decline as T. heterophylla and Cupressaceae increase. Alnus viridis and A. rubra types are common as well, though at lower values than in the previous Zone HL-2. An increase in Coptis is concomitant with a minor increase in Pinus around 7700 cal yr BP (6700 $^{14}$C yr BP) (Figure 6). Cupressaceae begins to occur more consistently and at increasing frequencies beginning at 6150 cal yr BP (5400 $^{14}$C yr BP). Pollen and spore concentrations range between 134,000–447,000 grains/cm$^3$. Trends in pollen concentrations of individual taxa are similar to percentage data, except the increase in T. heterophylla appears more gradual (Figure 7). The beginning of this zone corresponds to a sediment change from light-tan gyttja to brown, coarse detritus gyttja, which also characterizes the overlying sediment (Walker 1988). A modern Picea-T. heterophylla-Alnus pollen assemblage on Graham Island in Haida Gwaii (Heusser 1985) is analogous to the mixed Picea-T. heterophylla forest that characterizes Zone HL-3. The pollen assemblage in this zone is also similar to the modern pollen rain of three subalpine ponds in Haida Gwaii (i.e., SC-1 Pond, Shangri-La Bog, and Louise Pond); however, these modern pollen assemblages record greater percentages of T. heterophylla as well as a Cupressaceae component (Pellatt et al. 1997).

Zone HL-4: 65–0 cm; 4390 cal yr BP–present (3820 $^{14}$C yr BP–present)

Cupressaceae reaches co-dominant levels with Picea and Tsuga heterophylla at the boundary of Zone HL-3/4 and continues to rise to become the dominate source of
arboreal pollen (Figure 9). Polypodiaceae spores decrease slightly in this zone, but percentages around 20% are maintained (Figure 10). *Coptis, Lysichiton americanus,* and *Polypodium* values are also stable (Figure 8). *Alnus viridis* type and *A. rubra* type diminish, as do *Pinus contorta* type percentages. Pollen and spore concentrations range from 168,000–471,000 grains/cm$^3$, reaching their maximum for the period of record. The most significant contrast between percentage and concentration data is that Cupressaceae concentrations rise to peak values only once (Figure 7). Shangri-La Bog, just south of Hippa Island on the adjacent Graham Island (Figure 1), has a pollen assemblage similar to that of Zone HL-3b. The modern pollen assemblage of Shangri-La Bog is mostly mixed *Tsuga heterophylla*-Cupressaceae-*Picea* forest, with an *Alnus viridis* understory (Pellatt et al. 1997); however, unlike Hippa Lake, the subalpine bog also has a small, but significant *T. mertensiana* component. Small amounts of *Alnus rubra, Pinus contorta* type, and Ericaceae are common to both assemblages.

**Conifer Stomata**

Conifer stomata are present and well-preserved throughout most of the Hippa Lake sediment core (Figure 11). Occasional stomata presence in Zone HL-1 is noted by stomata concentrations that do not exceed 50 stomata/cm$^3$. There is a conspicuous lack of conifer stomata between 346–327.5 cm depth in Zone HL-2. A trend of elevated stomata concentrations is found in Zone HL-3; the maximum for the period of record (30,250 stomata/cm$^3$) is noted at 257.5 cm depth. Stomata concentrations decrease to about 3300 stomata/cm$^3$ in Zone HL-4.
Figure 11. Total conifer pollen percentages and concentrations, and conifer stomata counts and concentrations for Hippa Lake, with 50x exaggeration applied to stomata concentrations.
Vegetation History of Hippa Island

Pollen and spore percentage data and the presence of conifer stomata are used to reconstruct the post-glacial vegetation history of Hippa Island. Given the small size of Hippa Lake (3.2 ha), these data provide a record of local vegetation dynamics, with a small component of regional dynamics also included. A predominantly herbaceous vegetation assemblage is succeeded by *Pinus*-dominated woodlands during the late-glacial period. Holocene vegetation is characterized by mixed *Picea-Tsuga heterophylla* forests, which are joined by *Thuja plicata* prior to the late Holocene.

Late-Glacial Period

The Hippa Island record begins with a diverse herb and shrub assemblage at 13,980 cal yr BP (11,760 $^{14}$C yr BP) (Figures 7 and 8). Vegetation is mostly herbaceous and comprised largely of Cyperaceae and *Artemisia*. *Salix* is the most important shrub component, although ericaceous shrubs such as *Empetrum* are also present. Diverse herbaceous taxa are represented in the Hippa Lake pollen record, including various taxa of Asteraceae, Apiaceae, and Chenopodiaceae. Apiaceae diversity is the greatest during the late-glacial period and includes peak amounts of *Angelica*. The pollen and spores of several taxa are only found in the late-glacial record including *Stellaria* type, *Polemonium pulcherrimum*, *Campanula* type, *Cryptogramma*, and *Botrychium*.

Given the diversity of taxa, a variety of habitats likely existed on the late-glacial landscape. Low organic content in sediments and low pollen and spore concentrations (1,600–1,400 grains/cm$^3$) suggest that vegetation was discontinuous and resembled
tundra. Cyperaceae, the primary vegetation based on pollen abundance, consists of species with varying moisture requirements and likely inhabited a variety of sites ranging from somewhat dry to excessively wet. Moist, water-collecting depressions may have also been occupied by Apiaceae, Stellaria, and Ranunculus. Artemisia is an important secondary component and includes species that favour well-drained, poorly-developed soils. These sites may have supported Polemonium pulcherrimum, Campanula, and Cryptogramma as well; the latter two are indicators of dry, nitrogen-poor soils in open terrain (Klinka et al. 1989). The variety of pollen types, which includes both moist and dry habitat indicators, suggests a diversity of habitats on the landscape. This is not surprising given the adjacent subaerially-exposed terrain that would have existed off present-day Hippa Island (Hetherington et al. 2004), and the exposed mineral surfaces and networks of glacial meltwaters that would have existed during the late-glacial period.

Other vegetation reconstructions on Haida Gwaii also record diverse herb-shrub tundra during the late-glacial period (Figure 12). Some of these records precede 14,000 cal yr BP (12,000 $^{14}$C yr BP) and contain less Artemisia than the Hippa Lake sediments. Prior to 15,500 cal yr BP (13,000 $^{14}$C yr BP), vegetation on Haida Gwaii was mostly herbaceous and largely consisted of Cyperaceae, although Poaceae and other herbs were also present (Warner et al. 1982; Warner 1984; Lacourse et al. 2005). Salix and ericaceous shrubs join Cyperaceae after 15,500 cal yr BP (13,000 $^{14}$C yr BP). Despite Pinus replacing herb-shrub tundra by 14,000 cal yr BP (12,000 $^{14}$C yr BP) at most sites on Haida Gwaii (Mathewes and Clague 1982; Heusser 1995; Lacourse et al. 2003, 2005), herbs and shrubs appear to have dominated Hippa Island until 13,500 cal yr BP (11,400 $^{14}$C yr BP).
Figure 12. Summary of selected paleoecological studies.
Tundra vegetation on Hippa Island and throughout Haida Gwaii corroborates climate models that suggest a cold, late-glacial climate. Global climate simulations suggest that prior to 14,000 cal yr BP (12,000 \(^{14}\)C yr BP), climate was controlled by an anti-cyclonic high pressure system over the continental ice sheets which drove cold, dry continental air westward, a pattern supported by southern displacement of the jetstream (COHMAP 1988; Bartlein et al. 1998). Pollen-based climate reconstructions also suggest a cold, and possibly dry, climate prior to 14,000 cal yr BP (12,000 \(^{14}\)C yr BP) (Mathewes and Heusser 1981; Heusser 1985; Heusser et al. 1985). Chironomid-based paleoclimate estimates from Hippa Lake also suggest that temperatures were cooler than present (Walker and Mathews 1988).

Small amounts of \textit{Pinus contorta} type (<4%), \textit{Picea} (<4%), and \textit{Tsuga heterophylla} (<1%) pollen occur in late-glacial sediments at Hippa Lake (Figure 9). Trace amounts of conifer pollen are common in late-glacial, herb-dominated pollen records from the region (e.g., Warner 1984; Peteet 1991; Heusser 1995; Lacourse et al. 2005), but in the absence of stomata or macrofossil evidence, conifer pollen is usually interpreted to be the product of long-distance transport. At Hippa Lake, however, conifer pollen in late-glacial sediments is accompanied by conifer stomata (Figure 11). These conifer stomata suggest that at least some conifer pollen during the late-glacial period may be of local origin. Given that \textit{Pinus} expansion occurred prior to that of other conifers, \textit{Pinus} is the most likely source of conifer stomata in the Hippa Lake basal sediments. \textit{Pinus} has a wide edaphic tolerance and it is possible that it was able to grow on select sites amid a mostly tundra-like landscape. Scattered \textit{Picea} may have also existed on Hippa Island during the late-glacial period.
The presence of conifer stomata in the late-glacial herbaceous assemblage on Hippa Island (Figure 13) is not surprising when viewed in the context of regional studies. Trace amounts of *Pinus contorta* type pollen (i.e., ≤6%) have also been found with *Pinus* stomata in late-glacial sediments at West Side Pond on the west coast of Moresby Island in Haida Gwaii (Lacourse et al. 2005) and with *P. contorta* needles in peat sections near Yakutat in southeast Alaska (Peteet 1991). At West Side Pond, *Pinus* stomata begin appearing at 15,500 cal yr BP (13,000 \(^{14}\text{C}\) yr BP) when *P. contorta* type pollen is only 6% of the pollen sum (Lacourse et al. 2005). In Juan Perez Sound (Lacourse et al. 2003), abundant *P. contorta* type pollen, needles, and cones, as well as an *in situ* *Pinus* stump dated to 14,160 cal yr BP (12,240 ± 50 \(^{14}\text{C}\) yr BP; CAMS-59768) indicate that *Pinus* was locally present on the exposed continental shelf that would have existed at that time. Given the data from Hippa Lake, West Side Pond, and Juan Perez Sound, it appears likely that *Pinus* was present on Haida Gwaii by 15,500 cal yr BP (13,000 \(^{14}\text{C}\) yr BP). While herbs and shrubs may have persisted longer on Hippa Island, the presence of conifer stomata (likely *Pinus*) and *P. contorta* type pollen suggest that *Pinus* colonization on Hippa Island is synchronous with other sites on Haida Gwaii.

Cyperaceae initially remains abundant amid expansion of *Pinus* populations on Hippa Island around 13,250 cal yr BP (11,300 \(^{14}\text{C}\) yr BP), but most other herbs decline in abundance (Figure 8). *Salix* also declines as it is replaced briefly by *Empetrum* and then by *Alnus viridis* as the primary shrub component (Figure 9). The understory of open *Pinus* woodlands were dominated by light-demanding Polypodiaceae ferns, with increasing amounts of *A. viridis* beginning 13,000 cal yr BP (11,000 \(^{14}\text{C}\) yr BP).
Increases in Isoëtes, which likely grew mostly around the margins of the lake, coincide with the transition from tundra to woodlands.

*Figure 13. Conifer stomata (1000×) from sediment depth 352 cm, 13,800 cal yr BP (12,100 14C yr BP).*

*Pinus contorta* is well suited for invading herb-shrub tundra as it can withstand a wide range of soil moisture extremes and nutrient deficiencies (Klinka et al. 1989). Soils preceding *Alnus* and conifer establishment likely had low organic matter and low vegetation cover, as suggested by the low organic content of clayey sediments that precede the increase in *P. contorta* type pollen. *Valeriana sitchensis*, an indicator of nitrogen-rich soils (Klinka et al. 1989), does not occur in the Hippa Lake pollen record prior to *Pinus* establishment (Figure 8). Concurrent with the rise in *Pinus*, Hippa Lake sediments change to light-tan gyttja with increased organic matter.

Despite the presence of conifer stomata in the herb-dominated basal sediments, conifer stomata are absent during the *Pinus* interval (Figure 11). This could be attributed to the fact that conifer stomata deposition and preservation in lake sediments is similar to plant macrofossils (MacDonald 2001): the limited dispersal range of conifer stomata
serve as powerful indicators of local presence; however, their absence does not prove local absence on the landscape. Also, despite peak abundances of *P. contorta* type pollen percentages, values are lower than other nearby sites during the late-glacial *Pinus* interval. *Pinus contorta* type pollen percentages are greater than 80% at SGang gwaay (Hebda et al. 2005) (Figure 1) and in southeast Alaska on Pleasant Island (Engstrom et al. 1990; Hansen and Engstrom 1996). While these studies do not include fern spores in the pollen sum, fern exclusion alone does not explain the disparity in *Pinus* levels. Also, *P. contorta* type pollen percentages are higher in studies that include fern spores in the total pollen sum (e.g. 50%, West Side Pond (Lacourse et al. 2005)). While it is possible that *Pinus* expansion may have been more limited on Hippa Island; *Pinus contorta* type pollen abundances suggest that this species was the dominant component of the vegetation on Hippa Island at the time.

The rapid colonization of *Pinus* was likely facilitated by increased temperature during the summer growing period as well as increased precipitation. Climate models suggest increasing precipitation and seasonality during the latter part of the late-glacial period. After 14,000 cal yr BP (12,000 ¹⁴C yr BP), continental ice-sheets began to recede and this reduced the anti-cyclonic high that drove dry winds onto the Pacific Coast (COHMAP 1988; Bartlein et al. 1998). Moist westerlies became more pronounced (COHMAP 1988) and northward movement of the jetstream following reduction of continental ice increased regional precipitation (Bartlein et al. 1998). Fluctuations in solar insolation led to increased seasonality; while summer temperatures may have been somewhat higher, winter temperatures were cooler than present (Bartlein et al. 1998).
Younger Dryas Chronozone

The end of the Pleistocene is marked by a period of brief cooling and the re-advance of many glaciers, known as the Younger Dryas (Mangerud et al. 1974; Björck et al. 1998). While a causal mechanism for the Younger Dryas is still debated, the most common explanation is that a large influx of cold freshwater from melting of the Laurentide Ice Sheet entered the North Atlantic Ocean and temporarily reduced or shutdown the north Atlantic thermohaline circulation (Broecker 2006). Vegetation change associated with the Younger Dryas cooling is recorded at numerous sites around the north Atlantic by decreases in tree species and increases in herbs such as Poaceae and Cyperaceae (e.g., Mott et al. 1986; Shuman et al. 2002). There is also evidence for increased Juniperus, Poaceae, and Artemisia at other sites in the north Atlantic without corresponding decreases in tree taxa (Williams et al. 2002). Increases in Alnus pollen during the Younger Dryas are also common to many north Atlantic paleovegetation studies (Mayle et al. 1993). On the north Pacific coast, cooling may have occurred via atmospheric teleconnections with the north Atlantic (Mikolajewicz et al. 1997). Along the north Pacific coast, vegetation responses to Younger Dryas cooling (Lacourse 2007) include either regression from open woodland to Alnus shrub and/or herb-dominated assemblages (Engstrom et al. 1990; Mathewes et al. 1993; Hansen and Engstrom 1996) and/or increases in Tsuga mertensiana pollen (Mathewes 1993; Mathewes et al. 1993; Lacourse 2005).

A slight shift in vegetation occurs on Hippa Island at 12,500 cal yr BP (10,700 \(^{14}\)C yr BP), at the onset of Younger Dryas cooling, when a drop in Pinus contorta type from 35% to 5% coincides with increases in Picea, Alnus shrubs, ferns, and herbs (Figures 6,7, 8, 9, and10). A rise in Alnus viridis type is followed by A. rubra type, which
reach their maxima (23 and 10% respectively) for the period of record during the Younger Dryas chronozone. While a second peak in *A. viridis* follows *A. rubra* expansion, pollen concentration data places greater importance on the initial *A. viridis* increase, prior to *A. rubra* establishment (Figure 7). Peak percentages of Polypodiaceaee (43%) and *Athyrium felix-femina* (4.5%) fern spores also correspond well to the Younger Dryas chronozone. The increase in herbaceous taxa is largely driven by increasing Cyperaceae and *Artemisia*, but several wet meadow associates including *Caltha biflora*, *Angelica* type, *Osmorhiza*, *Sanguisorba*, *Gentiana douglasiana*, *Valeriana sitchensis*, and *Menyanthes trifoliata* are also recorded. While pollen percentages of herbaceous taxa increase only modestly, their pollen concentrations show a much greater relative increase during the Younger Dryas (Figure 7). *Pinus contorta* type pollen gradually increases, but does not return to pre-Younger Dryas levels; instead *Picea* becomes increasingly abundant.

Vegetation response to Younger Dryas cooling on Hippa Island is suggested by overall reduced conifer pollen (from 36% to 11%) and corresponding increases in herbs and ferns, but these changes are lower in magnitude compared to other studies in the region. For instance, on Pleasant Island in southeast Alaska, reductions in *Pinus* pollen from 80% to 10% are coupled with an increase in herbs to over 50% (Engstrom et al. 1990). Vegetation on Hippa Island does not show an increase in *T. mertensiana* as at other sites (Mathewes et al. 1993; Lacourse 2005), but increased *Alnus viridis*, Cyperaceae, and *Artemisia* amid decreased conifer presence is similar, albeit at a reduced magnitude, to the Pleasant Island pollen record (Engstrom et al. 1990; Hansen and Engstrom 1996). It is likely that cooling at Hippa Lake was not well recorded by
vegetation changes given the predominance of mesic taxa that were common on Hippa Island during the Younger Dryas. The vegetation response to Younger Dryas cooling also does not appear in the record from West Side Pond (Lacourse et al. 2005), another hypermaritime site approximately 135 km south of Hippa Island (Figure 1), which shows no detectable vegetation changes during this cool period.

While the vegetation changes that occurred on Hippa Island during the Younger Dryas are somewhat limited, decreased temperatures of 2–3°C are inferred from other nearby paleoecological records (Mathewes 1993; Mathewes et al. 1993). Terrestrial and marine records suggest that cooling occurred between 12,500–11,600 cal yr BP (10,700–10,000 $^{14}$C yr BP) on the British Columbia coast (Mathewes 1993). This estimate is based on decreased ocean temperatures in the northeast Pacific, which are inferred from coldwater benthic foraminifera (Mathewes et al. 1993; Patterson et al. 1995) and temperate bivalves (Hetherington and Reid 2003), as well as lower air temperatures based on pollen transfer functions from vegetation reconstructions (Mathewes et al. 1993). Differences between these paleoclimatic estimates and the vegetation on Hippa Island may be explained by the dominance of mesic taxa on Hippa Island during the Younger Dryas chronozone. It is also possible that the chronological resolution of the sediment samples was not great enough to capture a strong Younger Dryas signal, especially given that radiocarbon dates are based on bulk sediment sampling.

**Early Holocene**

A sharp change in vegetation occurs at the transition to the early Holocene with *Pinus, Alnus viridis,* and *Cyperaceae* giving way to *Picea, Tsuga heterophylla, Lysichiton americanus,* and *Polypodium* (Figure 6). The development of *Picea-T. heterophylla*
forest characterizes the early Holocene. These forests include an understory vegetation comprised largely of ferns and *A. viridis*, along with *L. americanus*. The absence of *Pinus* and the presence of *Picea* and *T. heterophylla* suggest the forest canopy became increasingly closed. The development of mixed forest communities corresponds to a stratigraphical transition in the Hippa Lake sediment core from light-tan gyttja to brown, coarse detritus gyttja and increased organic content, characteristic of subsequent Holocene sediments (Walker and Mathewes 1988).

The establishment of *Picea* forests was likely related in part to increased soil development, as soils rich in nutrients are required by *Picea* (Klinka et al. 1989). Organic matter content in the Hippa Lake sediment core begins to increase during *Pinus* and *Alnus* establishment. The expansion of *Picea* following increases in *Alnus* pollen suggests that *Alnus* increased soil nitrogen levels, facilitating *Picea* establishment. Modern successional studies (e.g., Chapin et al. 1994) have shown that *Alnus* facilitates *Picea* establishment and this pattern has been recorded at other sites in Haida Gwaii (Lacourse et al. 2005), in southeast Alaska (Hansen and Engstrom 1996), and on northern Vancouver Island (Lacourse 2005) (Figure 12).

Peak percentages of *Picea* during the early Holocene may reflect a combination of factors. *Picea* is less shade-tolerant than *Tsuga heterophylla* and *Thuja plicata* (Klinka et al. 1989) and canopy cover may have been somewhat more open than in subsequent Holocene forests. Interspecies competition with *T. heterophylla* may have become more important with an abrupt, albeit small increase in *T. heterophylla* percentages and overall decreases in *Picea* percentages (Figure 9) after 7900 cal yr BP (7000 \(^{14}C\) yr BP). *Tsuga heterophylla* pollen concentrations also appear to be much less in the early Holocene
(Figure 7). These minor vegetation changes may be indicative of a warmer, drier early Holocene period in which reduced humidity may have had a limiting effect on *T. heterophylla*, while decreased competition may have favoured *Picea* growth.

A continuous trend of increased stomata concentrations are found during the early Holocene interval between 11,000 and 8000 cal yr BP (9500 and 7000 $^{14}$C yr BP). These values can be attributed to a greater number of conifer needles being deposited into the lake. The apparent increase in deposited needles may signify increased moisture stress due to decreased precipitation during the early Holocene.

The establishment of mixed *Picea-Tsuga heterophylla* forest, with an understory of *Alnus* and Polypodiaceae ferns, is common at most early Holocene sites on Haida Gwaii (Warner 1984; Fedje 1993; Pellatt and Mathewes 1994, 1997; Heusser 1995; Hebda et al. 2005). Increases in *T. heterophylla* at subalpine sites (Pellatt and Mathewes 1994, 1997) and decreases at lowland sites (Warner 1984; Fedje 1993; Heusser 1995; Hebda et al. 2005) on Haida Gwaii may reflect warming and decreased precipitation during the early Holocene. Bog complexes, characteristic of modern, wet climate on Haida Gwaii, are not widespread until after 8000 cal yr BP (7000 $^{14}$C yr BP) (Warner 1984; Quickfall 1987; Fedje 1993; Pellatt and Mathewes 1994, 1997), which lends further support for a warmer, drier interval during the early Holocene.

Climate models suggest that increased summer insolation related to orbital variations was responsible for warmer-than-present summer temperatures during the early Holocene; however, winter temperatures were colder-than-present leading to increased seasonality (COHMAP 1988; Koerner and Fisher 1990; Bartlein et al. 1998). Reduced precipitation is also suggested by extra-regional climate models (e.g.,

At Hippa Lake, the best indicator of a warmer, drier early Holocene interval is the increase in stomata concentrations. This climate trend may have also been captured by somewhat heightened Picea values and suppressed pollen concentrations of Tsuga heterophylla between 11,000 and 8000 cal yr BP (9500 and 7000 $^{14}$C yr BP); however, a strong vegetation response to early Holocene climate change is not apparent in the pollen record. This difference suggests that the mesic plant species that typify the Hippa Lake pollen record are not strong indicators of climate change.

**Mid-Holocene**

Beginning about 7700 cal yr BP (6900 $^{14}$C yr BP), Picea, Alnus rubra, and Polypodiaceae gradually decline, but remain abundant, amid increasing Tsuga heterophylla (Figure 6). Cupressaceae pollen (assumed to be Thuja plicata) is noted at consistent, but low frequencies until 6150 cal yr BP (5400 $^{14}$C yr BP), when it begins increasing rapidly. Altogether, however, forests are similar to early Holocene communities; Picea and T. heterophylla dominate forests with an understory composed largely of Polypodiaceae ferns, A. viridis shrubs, and Lysichiton americanus. The arrival of T. plicata and Coptis (Figure 6), and minor increases in T. heterophylla, Pinus, Cyperaceae, and Caltha biflora suggest that precipitation may have increased; however, the magnitude of these changes is limited.

Bog complexes began forming at a number of sites on Haida Gwaii during the mid-Holocene (Warner 1984; Quickfall 1987; Pellatt and Mathewes 1994, 1997). The near synchronous timing of paludification across the archipelago suggests that the main
driver of bog development was an increasingly wet climate (Warner 1984; Quickfall 1987; Pellatt and Mathewes 1994, 1997). Cupressaceae pollen begins appearing around 7000 cal yr BP (6000 $^{14}$C yr BP) in records from Haida Gwaii (Warner 1984; Quickfall 1987; Pellatt and Mathewes, 1994, 1997; Hebda et al. 2005). This trend was also found in a review of Cupressaceae pollen records from throughout the north Pacific coast (Hebda and Mathewes 1984) that attributed these synchronous expansions to an increasingly wetter, cooler climate.

Climate models also point to progressively increasing moisture and decreasing temperatures in the latter half of the Holocene, as insolation decreased and the Aleutian low-pressure centre became more pronounced (Heusser 1985; COHMAP 1988; Koerner and Fisher 1990; Bartlein et al. 1998). Pollen-based estimates of paleoclimate from southeast Alaska (Heusser 1995), southern British Columbia (Mathewes and Heusser 1981), and western Washington (Heusser 1985) reflect increased precipitation and decreased temperature beginning in the mid-Holocene as well. Warner (1984), Fedje (1993), and Hebda (1995) suggest that increases in precipitation preceded decreased temperature. Collectively, climate evidence suggests that the mid-Holocene was a period of transition from warm and dry to cool and moist.

The most substantial evidence for this climate transition from the Hippa Island vegetation record is the arrival and subsequent increase in Cupressaceae pollen. This rise may be partially attributed to nearby bog development, which also likely contributed to abrupt and simultaneous, albeit minor, increases in *Caltha biflora* and *Coptis* pollen. Aside from the notable trajectory of increased Cupressaceae pollen, long-term vegetation trends during the mid-Holocene are mostly stable.
**Late Holocene**

Marked expansion of presumably *Thuja plicata* populations led it to become a dominant arboreal component after 4500 cal yr BP (4000 $^{14}$C yr BP) (Figure 9). Modern mixed *T. plicata*-*Picea sitchensis*-*Tsuga heterophylla* forest was subsequently formed. Pollen concentration data suggests that *Thuja plicata* reached peak abundance around 2900 cal yr BP (2500 $^{14}$C yr BP). The understory vegetation remains similar in composition to the mid-Holocene with Polypodiaceae ferns, *Alnus viridis*, and *Lysichiton americanus* dominant, but these taxa appear at somewhat reduced percentages of the pollen sum—likely a statistical artefact of increased Cupressaceae pollen.

Regional studies suggest that cooler temperatures and increasing moisture allowed *Thuja plicata* to increase to dominate forests along with *Picea* and *Tsuga heterophylla* in the late Holocene (Hebda and Mathewes 1984; Warner 1984; Quickfall 1987; Fedje 1993; Pellatt and Mathewes 1994, 1997; Heusser 1995). There is some suggestion of increased cooling on Haida Gwaii around 3200 cal yr BP (3000 $^{14}$C yr BP) that corresponds to glacial advances in the Coast Mountains (Fedje 1993; Pellatt and Mathewes 1994, 1997). While, this acute cool period is not apparent in the pollen percentage data from Hippa Lake, a peak in *T. plicata* pollen concentrations between 3200 and 2500 cal yr BP (2800 and 2200 $^{14}$C yr BP) may signify elevated precipitation and reduced temperature. *Thuja plicata* appears to be a stronger indicator of climate variability than the other, more mesic taxa that dominate the Hippa Lake Holocene record.

The Aleutian low-pressure centre continued to intensify in the late Holocene, increasing storm activity and bringing cooler temperatures and wetter climate to the British Columbia coast (Heusser 1985; COHMAP 1988; Bartlein et al. 1998). Cool, wet
climate is also reflected in pollen-based climate reconstructions for the region (Heusser 1985, 1995; Mathewes and Heusser 1985). Additionally, glacial advances during the late Holocene, perhaps related to brief periods of cooling and/or increased precipitation, are noted in a number of studies in the Coast Mountains (e.g. Clague 1981; Ryder and Thomson 1986; Clague and Mathewes 1996; Lamoureux and Cockburn 2005; Arsenault et al. 2007; Jackson et al. 2008). Increased moisture and decreased temperature during the late Holocene likely facilitated the expansion of *Thuja plicata* on Hippa Island.

**Regional Context**

In general, the timing of the establishment of major tree taxa on Hippa Island is similar to other sites on Haida Gwaii, and for the most part, the rest of the north Pacific coast (Figure 12). Pollen and conifer stomata microfossils from Hippa Lake corroborate other studies from Haida Gwaii that indicate that *Pinus* was present on the archipelago by 14,200 cal yr BP (12,300 $^{14}$C yr BP); however, *Pinus* expansion appears somewhat delayed on Hippa Island compared to other nearby sites. The early arrival of *Pinus* following deglaciation suggests that *Pinus* survived in coastal refugia or was able to rapidly migrate from ice-free areas outside the extent of Late Wisconsin ice, either from the north in interior Alaska (Matthews 1974; Ager 1983) or Yukon (Rampton 1971), or from the south in Western Washington (Heusser 1995). Potential *Pinus* seed sources within the extent of ice include coastal refugia in southeastern Alaska, such as the Alexander Archipelago (Heusser 1954; Harris 1965; Worley and Jacques 1973) and north Vancouver Island (Hebda 1983), including Brooks Peninsula (Hebda 1997). In addition, portions of the continental shelf, including northern Vancouver Island (Luternauer et al. 1989; Lacourse et al. 2003) and Hectate Strait (Barrie et al. 1993; Fedje
and Josenhans 2000; Lacourse et al. 2003, 2005; Lacourse 2004; Lacourse and Mathewes 2005), were subaerially exposed and inhabited by *Pinus* during the late-glacial period. These ice-free areas may have served as a migration corridor for *Pinus* and other plants along the north Pacific coast.

The earliest *Picea* record on Haida Gwaii is from the sea-cliffs at Cape Ball, where pollen and macrofossil evidence suggests that *Picea* was present by 14,000 cal yr BP (12,000 $^{14}$C yr BP). Lacourse (et al. 2005) found *Picea* pollen and needles in sediment from West Side Pond deposited around 13,500 cal yr BP (11,500 $^{14}$C yr BP). *Picea* was likely present on Haida Gwaii after 13,200 cal yr BP (11,200 $^{14}$C yr BP) (Warner 1984; Lacourse 2004; Lacourse and Mathewes 2005; Lacourse et al. 2005; Hebda et al. 2005); however, *Picea* does not begin to expand on Hippa Island until 12,500 cal yr BP (10,700 $^{14}$C yr BP). Prior to deglaciation, *Picea* populations existed south of continental ice sheet in western Washington (Heusser 1995). *Picea* began increasing at a number of sites on Vancouver Island by 14,000 cal yr BP (12,000 $^{14}$C yr BP) (Hebda 1983; Hebda 1997; Brown and Hebda 2002, Brown and Hebda 2003; Lacourse 2005) and on the British Columbia mainland (Mathewes 1973; Pellatt et al. 2002) by 13,500 cal yr BP (11,400 $^{14}$C yr BP). *Picea* expansion was delayed until about 11,000 cal yr BP (9500 $^{14}$C yr BP) in southeastern Alaska (Cwynar 1990; Hansen and Engstrom 1996). Given the nearby presence of *Picea* elsewhere on Haida Gwaii, the slight delay in *Picea* establishment on Hippa Island is likely not a migrational lag, but rather a reflection of unfavourable site conditions, such as insufficient soil development within the island’s rocky, exposed headlands.
Pollen and macrofossil evidence suggests that *Tsuga heterophylla* was present at Cape Ball by 12,500 cal yr BP (10,700 $^{14}$C yr BP). By 11,000 cal yr BP (9750 $^{14}$C yr BP), *T. heterophylla* began increasing at sites around Haida Gwaii (Warner 1984; Lacourse 2004; Lacourse and Mathewes 2005; Lacourse et al. 2005), including on Hippa Island. *Tsuga heterophylla* joined the coastal forests of mainland British Columbia (Mathewes 1973; Pellatt et al. 2002) and Vancouver Island beginning 11,600 cal yr BP (10,000 $^{14}$C yr BP) (Hebda 1983; Hebda 1997; Brown and Hebda 2002, Brown and Hebda 2003; Lacourse 2005). In southeastern Alaska, *T. heterophylla* did not flourish until (8000-8500 $^{14}$C yr BP). The arrival of *T. heterophylla* precedes actual expansion by several millennia at numerous sites on the north Pacific coast (e.g., West Side Pond, Fedje 1993; SGang gwaay, Hebda et al. 2005; Marion and Surprise Lakes, Mathewes 1973). By contrast, *T. heterophylla* expansion appears to occur immediately upon arrival on Hippa Island.

*Thuja plicata* began expanding across the Haida Gwaii archipelago beginning around 7000 cal yr BP (6000 $^{14}$C yr BP), as suggested by increases in Cupressaceae pollen (Warner 1984; Quickfall 1987; Fedje 1993; Pellatt and Mathewes, 1994, 1997; Hebda et al. 2005). On Hippa Island, *T. plicata* arrived around this time as well. Likewise, in southwestern British Columbia, *T. plicata* expansion was delayed until 7000 cal yr BP (6000 $^{14}$C yr BP); however, macrofossil evidence suggests it was present at Marion Lake as early as 11,200 cal yr BP (10,000 $^{14}$C yr BP) (Mathewes 1973). While many sites on Vancouver Island were also not heavily inhabited by *T. plicata* until the mid-Holocene (Hebda 1983, Hebda 1997, Brown and Hebda 2002, Brown and Hebda 2003), portions of Brooks Peninsula supported mixed *T. heterophylla-T. plicata* forest as early as 10,200 cal yr BP (9000 $^{14}$C yr BP) (Hebda 1997) and the Misty Lake area was
inhabited by *T. plicata* beginning 8200 cal yr BP (7500 $^{14}$C yr BP) (Lacourse 2005). While *T. plicata* does not appear to expand at most sites on the north Pacific coast until after 7000 cal yr BP (6000 $^{14}$C yr BP), some sites on north Vancouver Island appear to have permitted earlier expansion. Despite being present earlier, *T. plicata* does not expand until the cooler, more moist mid-Holocene at most sites on the north Pacific coast.

The remote, offshore location of Hippa Island along the west coast of the Haida Gwaii archipelago provides interesting insight into the north Pacific coast migration dynamics of major tree taxa. While delays in expansion of *Pinus* and *Picea* are noted in the Hippa Lake’s vegetation history, they are likely more related to site conditions on the exposed island rather than physiographic barriers. This interpretation is suggested by early conifer stomata presence, and is further supported by stratigraphic evidence and comparison to other nearby vegetation records.
Chapter 5: Conclusion

Summary

The Hippa Lake vegetation reconstruction begins at 14,000 cal yr BP (12,000 $^{14}$C yr BP) with a diverse herb and shrub assemblage dominated by Cyperaceae, Artemisia, and Salix, which persists until 13,450 cal yr BP (11,400 $^{14}$C yr BP). Pinus expansion on Hippa Island is not apparent in the pollen record until 13,250 cal yr BP (11,300 $^{14}$C yr BP) although stomata and pollen evidence suggests that Pinus may have been present locally as early as 14,000 cal yr BP (12,000 $^{14}$C yr BP).

Decreases in Pinus and minor increases in Picea, shrubs, herbs, and ferns correspond to the onset of Younger Dryas cooling 12,500 cal yr BP (10,700 $^{14}$C yr BP). These changes in the pollen record are similar to those of other paleoecological records from the region, but the reduced magnitude of the vegetation changes on Hippa Island suggest that mesic taxa were not strong indicators of climate change.

Abrupt vegetation change is noted at 10,900 cal yr BP (9550 $^{14}$C yr BP) as Pinus, Alnus viridis, and Cyperaceae gave way to Picea, Tsuga heterophylla, and Lysichiton americanus. Once established, mixed Picea-T. heterophylla forest and associates (e.g., Polypodiaceae ferns) occur at relatively stable proportions throughout the Holocene; however, heightened stomata concentrations, limited T. heterophylla pollen concentrations, and a minor increase in Picea corresponds well with reduced moisture and warmer temperatures during the early Holocene. Cupressaceae (Thuja plicata) is common after 6000 cal yr BP (5300 $^{14}$C yr BP) and becomes a major element of the vegetation on Hippa Island by 4500 cal yr BP (4000 $^{14}$C yr BP). While evidence of a
warmer, drier early Holocene is minimal in the Hippa Lake vegetation record, minor increases in *T. heterophylla* and the abundance of Cupressaceae suggest that increased relative moisture characterized Hippa Island by the late Holocene.

The relatively stable vegetation history suggests that mesic plant communities on Hippa Island are not strong indicators of climate change. Despite limited vegetation change, large-scale climate fluctuations are known to have occurred. It is likely that the mesic plant species of Hippa Island tolerated these climate variations, resulting in pollen assemblages that are relatively stable and overall resistant to climate change. The most substantial vegetation changes generally occurred during the late-glacial period over short time intervals and are likely related to plant migrations, changing autogenic factors, and/or dramatic climatic conditions that characterize the late-glacial environment. Following the development of Holocene forests, marked vegetation change is limited to the rise in *Thuja plicata*. Resilient, mesic vegetation communities on Hippa Island appear resistant to known climate change and links between vegetation and climate are limited in magnitude.

More substantial interactions between climate and vegetation are found in vegetation records from other sites on Haida Gwaii (see Figure 1) inhabited by vegetation communities that are more vulnerable to climatic shifts, such as those from subalpine areas adjacent to the treeline (i.e. Louise Pond, SC1 Pond, Shangri-La Bog; Pellatt and Mathewes 1994, 1997) and those adjacent to bog sites (i.e. Serendipity Bog Lake, Boulton Lake; Warner 1984; Argonaut Hill Bog, Drizzle Pit Bog, Kunghit Island; Quickfall 1987; Langara Island, Heusser 1995). Subalpine plant assemblages represent a transition zone from lowland forest to montane habitat and are more vulnerable to subtle
climatic fluctuations. Likewise, water-logged peat bogs are maintained by a delicate hydrologic balance and the hydric vegetation communities they support are more susceptible to climate change. By comparison, Hippa Island is characterized by sloped headlands and an equable, mild hypermaritime climate. These conditions favour mesic species which will not respond to climate fluctuations as readily as subalpine or peatland plant communities that depend on environmental extremes.

**Significance**

Few vegetation records spanning the late-glacial period to present have been reconstructed from sites on Haida Gwaii. Such continuous records are important for studying the migration dynamics of major tree taxa following deglaciation. Understanding the migration patterns of these species are useful in revealing potential areas that may have served as glacial refugia or late-glacial seed sources, reconstructing the development of coastal forests, and analyzing regional climate-vegetation interactions. In addition, the remote, outer west coast of Haida Gwaii has been subjected to few well-dated paleoecological reconstructions. Hippa Lake’s continuous record of vegetation history from the late-glacial period to present and its isolation from other paleoecological studies makes it useful for increasing the understanding of spatial vegetation dynamics such as tree species migrations along the north Pacific coast.

The presence of conifer stomata, likely *Pinus*, during the late-glacial herbaceous period suggests that *Pinus* grew locally prior to marked increase in *P. contorta* type pollen. This adds to a growing body of evidence (e.g. Peteet 1991; Lacourse et al. 2005) that trace amounts of conifer during the late-glacial herbaceous period may be attributed
to local presence. This finding has implications for the perceived source of conifer pollen contained in the predominantly herbaceous late-glacial records of the north Pacific coast.

Hippa Island’s hypermaritime climate and its geologic limitations for bog formation provide a unique paleoecological perspective. These factors helped shape vegetation history and may have limited plant communities to predominantly mesic taxa. As a relatively stable record of vegetation change, the Hippa Lake reconstruction gives an account of resilient vegetation communities resistant to large scale changes in climate. This resiliency is of key importance and should be explored further given the scale of environmental changes taking place in the modern world.

**Recommendations for future research**

Relative sea levels on the outer west coast of Haida Gwaii prior to the deglaciation of the British Columbia mainland were as low as or lower than central Hecate Strait (Hetherington et al. 2004). At present, no studies have been conducted to determine if the subaerially-exposed continental slope immediately west of Haida Gwaii supported vegetation as was the case at Dogfish Bank in Hecate Strait (Lacourse et al. 2005), at Cook Bank north of Vancouver Island (Lacourse et al. 2003), and adjacent to Bear Cove Bog, on northern Vancouver Island (Hebda 1983). Proximity to the edge of the continental shelf, steep elevation gradients of the continental slope, and strong hypermaritime influences may have limited ice extent on the west coast of Haida Gwaii; some ice-free terrain may have been available for plant habitation and may have possibly supported refugia for plants and animals during the last glacial period. Perhaps a renewed search for a continuous vegetation record spanning the last glaciation will identify possible ice-free areas along the outer west coast. Given sea-level fluctuations, the mid-
Wisconsin peat record at Pilot Mill (Warner et al. 1984), and the late-Wisconsin record at the Cape Ball seacliffs (Warner et al. 1982; Warner 1984), researchers may need to look beyond present-day lakes and bogs to find a vegetation record that spans the entire Wisconsin glaciation. Such a finding may help clarify the timing of *Abies* extirpation from Haida Gwaii, account for the diversity of taxa present at sites such as Hippa Lake and Cape Ball (Mathewes and Clague 1982; Warner 1984) that were deglaciated prior to the British Columbia mainland, and explain the presence of several endemic plants and animals on Haida Gwaii archipelago.

Future paleoecological research on Haida Gwaii should include plant macrofossil analysis, accelerator mass spectrometry (AMS) radiocarbon dating, and high-resolution sediment sampling; the absences of these were major limitations to the research conducted at Hippa Lake. Plant macrofossil and/or stomata data is critical in determining the arrival of major plant taxa, as macrofossil or stomata evidence has been found in sediments with only traces of associated pollen (e.g., Peteet 1991; Lacourse et al. 2005; this study). Identification of conifer stomata found in Hippa Lake sediments would confirm which conifer species were present locally during the herb and shrub dominated late glacial period. Future researchers should also focus on dating plant macrofossils using AMS radiocarbon dating as opposed to conventional radiocarbon dating of bulk sediment. Refined dating techniques, in combination with high-resolution sediment sampling, will help clarify the exact nature and timing of vegetation changes.

Lastly, the relationship between maritime climate and vegetation response within coastal communities warrants further investigation. While vegetation records are the result of an array of both autogenic and abiotic factors, future paleoecological inquires
pertaining to climate should continue to seek local, independent paleoclimate records for climate-vegetation comparisons. Underscoring this importance is the need for isolating autogenic factors from climatic variables in order to better understand the processes that drive vegetation change.
References


Hebda, R.J. 1995. British Columbia vegetation and climate history with focus on 6 Ka BP. *Géographie physique et Quaternaire* 49, 55–79.


History and Environment from the Time of Loon to the Time of the Iron People.


Lacourse, T. 2005. Late Quaternary dynamics of forest vegetation on northern Vancouver Island, British Columbia, Canada. Quaternary Science Reviews 24, 105–121.


