Article

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Richard J. Hebda

Géographie physique et Quaternaire, vol. 49, n° 1, 1995, p. 55-79.

Géographie physique et Quaternaire, 1995, vol. 49, n° 1, p. 55-79, 9 fig., 1 tabl.

BRITISH COLUMBIA VEGETATION AND CLIMATE HISTORY WITH FOCUS ON 6 KA BP

Richard J. HEBDA, Botany and Earth History, Royal British Columbia Museum, Victoria, British Columbia V8V 1X4, and Biology Department and School of Earth and Ocean Sciences, University of Victoria, P.O. Box 1700, Victoria, British Columbia V8W 2Y2.

ABSTRACT British Columbia Holocene vegetation and climate is reconstructed from pollen records. A coastal *Pinus contorta* paleobiome developed after glacier retreat under cool and probably dry climate. Cool moist forests involving *Picea, Abies, Tsuga* spp., and *Pinus* followed until the early Holocene. *Pseudotsuga menziesii* arrived and spread in the south 10 000-9000 BP, and *Picea sitchensis - Tsuga heterophylla* forests developed in the north. *T. heterophylla* increased 7500-7000 BP, and Cupressaceae expanded 5000-4000 BP. Bogs began to develop and expland. Modern vegetation arose 4000-2000 BP. There were early Holocene grass and *Artemisia* communities at mid-elevations and pine stands at high elevations in southern interior B.C. Forests expanded downslope and lakes formed 8500-7000 BP. Modern forests arose 4500-4000 BP while lower and upper tree lines declined. In northern B.C. non-arboreal communities preceded middle Holocene *Picea* forests. *Abies, Pinus* and *Picea mariana* predominated at various sites after 4000 BP. At 6000 BP *Tsuga heterophylla* (south) and *Picea sitchensis* (north) dominated the coast and islands and *Quercus garryana* and *Pseudotsuga* on southeast Vancouver Island, but *Thuja plicata* was infrequent. Southern Interior Plateau vegetation at 6000 BP was more open than today at middle to lower elevations, whereas forests covered the Northern Interior Plateau. *Picea* forests occurred in northern B.C. Holocene climate phases were : 1) warm dry "xerothermic" *ca.* 9500-7000 BP, 2) warm moist "mesothermic" *ca.* 7000-4500 BP, 3) moderate and moist 4500-0 BP, with increasing moisture 8500-6000 BP and cooling (?increased moisture) 4500-3000 BP. B.C.'s Hypsithermal had dry and wet stages; 6000 BP occurred in the warm and wet mesothermic stage.

RÉSUMÉ *Histoire du climat et de la végétation de la Colombie-Britannique, notamment de la période de 6 ka BP.* Cette reconstitution a été effectuée à partir des données polliniques. Un paléobiome à *Pinus contorta* s'est établi après le retrait des glaciers sous un climat frais et probablement sec. Des forêts de climat frais et humide à dominance de *Picea, Abies, Tsuga* spp. et *Pinus* ont suivi, jusqu'à l'Holocène inférieur. *Pseudotsuga menziesii* s'est ensuite répandu dans le sud de 10 000 à 9000 BP, tandis que les forêts à *Picea sitchensis - Tsuga heterophylla* se sont répandues dans le nord. *T. heterophylla* s'est accru de 7500 à 7000 BP et Cupressaceae s'est répandu de 5000 à 4000 BP. La végétation moderne s'est manifestée de 4000-2000 BP. Dans le sud de la partie intérieure, il y a eu des herbes et des communautés *d'Artemisia* aux altitudes moyennes et des peuplements de pins en haute altitude au début de l'Holocène. Les forêts modernes se sont formées de 4500 à 4000 BP, tandis que les limites des arbres déclinaient. Au nord, les communautés non arboréennes ont précédé les forêts de pins de l'Holocène moyen. *Abies, Pinus* et *Picea mariana* ont prédominé en différents sites après 4000 BP. À 6000 BP, *Tsuga heterophylla* (au sud) et *Pinus sitchensis* (au nord) ont dominé sur les côtes et les îles et *Quercus garryana* ainsi que *Pseudotsuga*, le sud-est de l'île de Vancouver. La végétation du sud du plateau intérieur à 6000 BP était plus ouverte que maintenant aux altitudes moyennes et basses, tandis que les forêts couvraient le nord du plateau intérieur. Les forêts de *Picea* occupaient le nord de la Colombie-Britannique. Les phases climatiques à l'Holocène sont les suivantes ; 1) une phase chaude et sèche, dite xérothermique, vers 9500-7000 BP, 2) une phase chaude et humide dite mésothermique, vers 7000-4500 BP, 3) une phase tempérée et humide de 4500 à 0 BP, avec une humidité croissante de 8500 à 6000 BP et un refroidissement (et humidité croissante ?) de 4500-3000 BP. À l'hypsithermal, le climat était tantôt sec, tantôt humide.

ZUSAMMENFASSUNG *Geschichte der Vegetation und des Klimas in British Columbia während des Holozäns, besonders um 6 ka v.u.Z.* Ein Küsten-Paläobiom mit *Pinus contorta* entwickelte sich nach dem Rückzug des Gletschers während eines kalten und wohl trockenen Klimas. Darauf folgten kalte feuchte Wälder mit *Picea, Abies, Tsuga* spp. und *Pinus* bis zum frühen Holozän. *Pseudotsuga menziesii* breitete sich dann in Süden von 10 000 bis 9000 v.u.Z. aus, und *Picea sitchensis-Tsuga*-Wälder entwickelten sich im Norden. *T. heterophylla* nahm von 7500-7000 v.u.Z. zu, und Cupressaceae etablierte sich von 5000-4000 v.u.Z. Sümpfe begannen zu entstehen und sich auszubreiten. Es gab im frühen Holozän Gras- und Artemisia-Einheiten in mittleren Höhen und Kiefer-Populationen in großen Höhen im südlichen Innern von British Columbia. Moderne Wälder entstanden zwischen 4500-4000 v.u.Z. während die untere und obere Baumgrenze zurückgingen. In Nord-B.C. gab es nichtbaumartige Einheinten vor den *Picea*-Wäldern des mittleren Holozän. An verschiedenen Plätzen dominierten *Abies, Pinus* und *Picea mariana* nach 4000 v.u.Z. Um 6000 v.u.Z. dominierten an der Küste und auf den Inseln *Tsuga heterophylla* (im Süden) und *Picea sitchensis* (im Norden) und *Quercus garryana* und *Pseudotsuga* im Südosten der Insel Vancouver, aber *Thuja plicata* war selten. Die Vegetation im Süden des inneren Plateaus um 6000 v.u.Z. war offener als heute in mittleren und niedrigen Höhen, während Wälder das nördliche innere Plateau bedeckten. *Picea*-Wälder gab es in Nord-B.C. Die Klimaphasen im Holozän waren:1) eine warme trockene "xerothermische", Phase etwa 9500-7000 v.u.Z., 2) eine warme feuchte "mesothermische" Phase etwa 7000-4500 v.u.Z., eine gemäßigte und feuchte Phase 4500-0 v.u.Z., mit zunehmender Feuchtigkeit von 8500-6000 v.u.Z. und Abkühlung (und zunehmender Feuchtigkeit?) 4500-3000 v.u.Z.

Manuscrit reçu le 9 septembre 1994 ; manuscrit révisé accepté le 17 janvier 1995

INTRODUCTION

British Columbia exhibits a diverse and complex landscape which supports more plant and animal species and more major ecological types than any other part of Canada. This physical and biotic variability provides an opportunity to examine broad ecological and climatic changes on a landscape where steep climatic and ecological gradients occur. As a consequence, lake and wetland sediment sequences were sensitive to past climatic changes. Unfortunately, the climate history of B.C. has yet to be studied as comprehensively as have other provinces and territories (Ritchie, 1987). Nevertheless, in the southern half of the province, there are sufficient sites to establish a broad outline of the character of vegetation and climate of the 6000 BP horizon. In the northern half of the province sites are scarce and available records provide only a glimpse at the time of interest. This paper will: 1) establish the physiographic, climatic and ecologic framework, 2) describe the general postglacial vegetation and climatic trends to establish a context for 6000 BP, and 3) discuss the vegetation and climate at 6000 BP in detail. The paper summarizes previous pollen studies, includes two new studies, and compiles data for 6000 BP from published and unpublished pollen sites throughout the province.

PHYSIOGRAPHY AND CLIMATE

British Columbia's physiography strongly shapes its climate and vegetation. The province comprises five broad physiographic units (Fig. 1): Coast Mountains and Islands, Interior Plateau, Columbia Mountains and Southern Rockies, North and Central Plateaus and Mountains, and Great Plains (Pojar and Meidinger, 1991).

In the west, the Coast Mountains and Islands unit includes the mountainous terrain of Vancouver Island, the Queen Charlotte Islands, and parts of the St. Elias Mountains. A low-lying or submerged coastal trough separates these mountains from the Coast Mountains on the mainland in the east. This is a high relief terrain largely dominated by glacial landforms and erosion surface remnants. Lower elevation slopes may exhibit less rugged terrain underlain by glacial drift and recent alluvial-fluvial deposits.

The Interior Plateau encompasses a large expanse of flat to gently rolling uplands between the Coast Mountains and Columbia Mountains and Southern Rockies unit. The southern third is dissected and relatively rugged and includes several highland subunits and deep steep-sided valleys. The northern two-thirds exhibits subdued topography with the Fraser River and tributaries responsible for major relief. Glacial drift covers most of the unit.

The Columbia Mountains and Southern Rockies occupy the southeast portion of the province. This unit comprises rugged mountain belts, separated by valleys, trending nearly north-south to northwest-southeast. Colluvium and bedrock predominate on upper slopes, but glacial drift and fluvial deposits predominate on gentle slopes of valley bottoms.

The Northern and Central Plateaus and Mountains Physiographic unit consists of a complex pattern of mountains, plateaus and plains in the northern third of the province. Here the mountain ranges are lower and less rugged than in the south and along the coast, separated by several flat to rolling plateaus and plains. The surface is largely underlain by glacial drift, thin on the mountains but thick on the less rugged terrain.

The last major unit, the Great Plains, in northeastern B.C., is an extension of flat to rolling landscape of the Canadian Prairies. In British Columbia there is little relief except where the Peace and Liard River systems are incised into the plateau. Glacial drift predominates as surface cover and extensive lacustrine clay and silt patches occur.

British Columbia's climate falls into three broad climatic regions; Pacific Canada (PC), Cordilleran Canada (CC), and Boreal (Hare and Thomas, 1979). In PC mild moist Pacific air predominates west of the Coast and Cascade Mountains summits. Winters are mild, cloudy and wet, whereas summers are moderate and relatively dry. The CC climate, which encompasses most of the province east of the coast, resembles that of the continental interior with cold winters and warm to hot summers. Deep southern valleys are especially arid and hot in the summer, and cool to cold in the winter. Slopes, peaks and plateaus are generally moister. The northern part of the region is strongly influenced by cold dry Arctic air in the winter. The northern fifth of the province falls into the Boreal zone. Winters are cold, but summers are moderate because of a stronger influence from Pacific air than in the rest of Canada. The national classification oversimplifies the complexity of the province's climate, in particular because of the role of elevation and related temperature lapse rates, and the orographic effects of mountain ranges, arranged largely perpendicular to the dominant pattern of air flow.

ECOSYSTEMS AND VEGETATION

National classification schemes for vegetation and ecological units (Rowe, 1972; Ecoregions Working Group, 1989) understate the ecological complexity of the British Columbia landscape and have limited value in interpreting vegetation climate and history. Consequently I use the widely-accepted biogeoclimatic zone system (Meidinger and Pojar, 1991), and describe the zones in detail because the system is probably unfamiliar outside of the province.

The provincial biogeoclimatic system combines characteristics of climate, physiography (soils) and zonal vegetation to identify and describe major units (Fig. 2). Essentially this is a vegetation-based system because "vegetation is considered to be the best integrator of environmental factors ... and because floristic criteria can be used to differentiate units" (Pojar *et al.*, 1991: 18).

Fourteen biogeoclimatic zones are recognized (Fig. 2), ranging from coastal conifer rainforests to arid shrub steppe and grassland, to boreal conifer forests and alpine tundra (Research Branch, 1988). Low to moderate elevations of the mild moist coast support the Coastal Western Hemlock

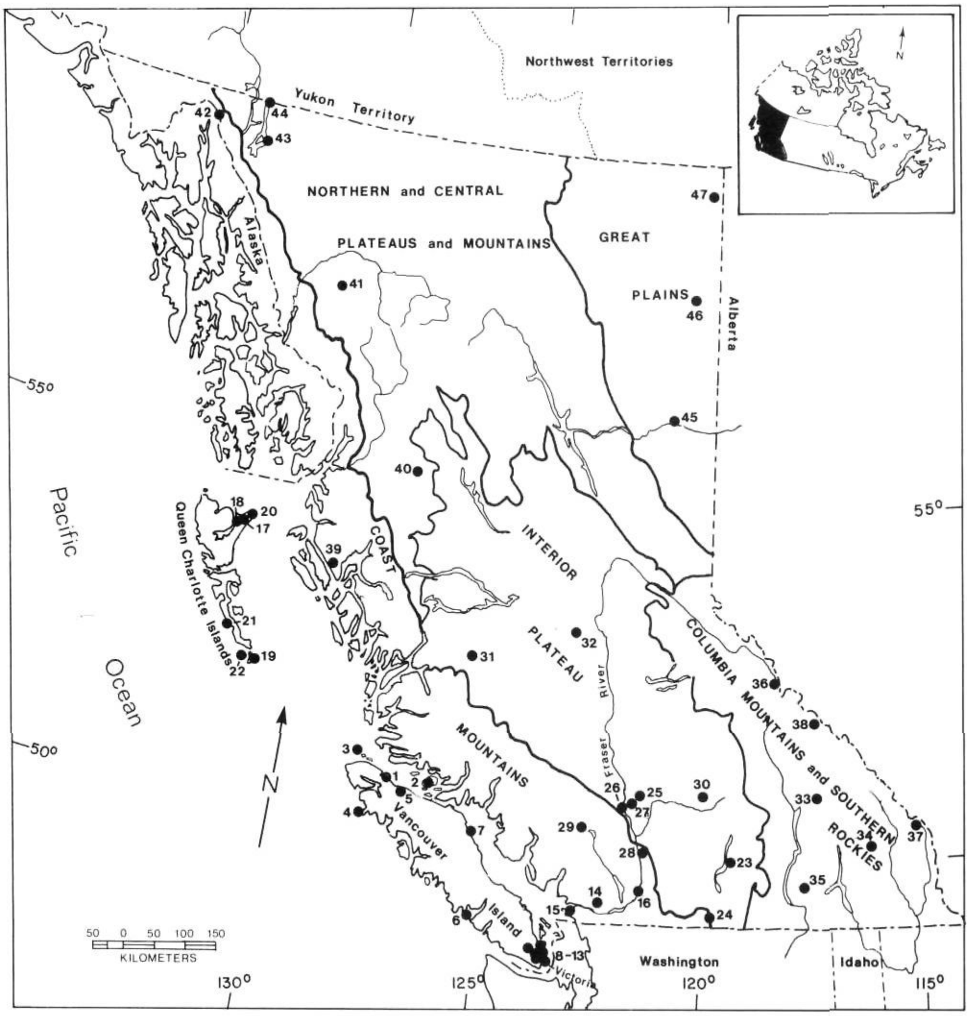


FIGURE 1. Major physiographic units of British Columbia, with location of 6000 BP sites.

Principales unités géophysiques de la Colombie-Britannique et localisation des sites de 6 ka.

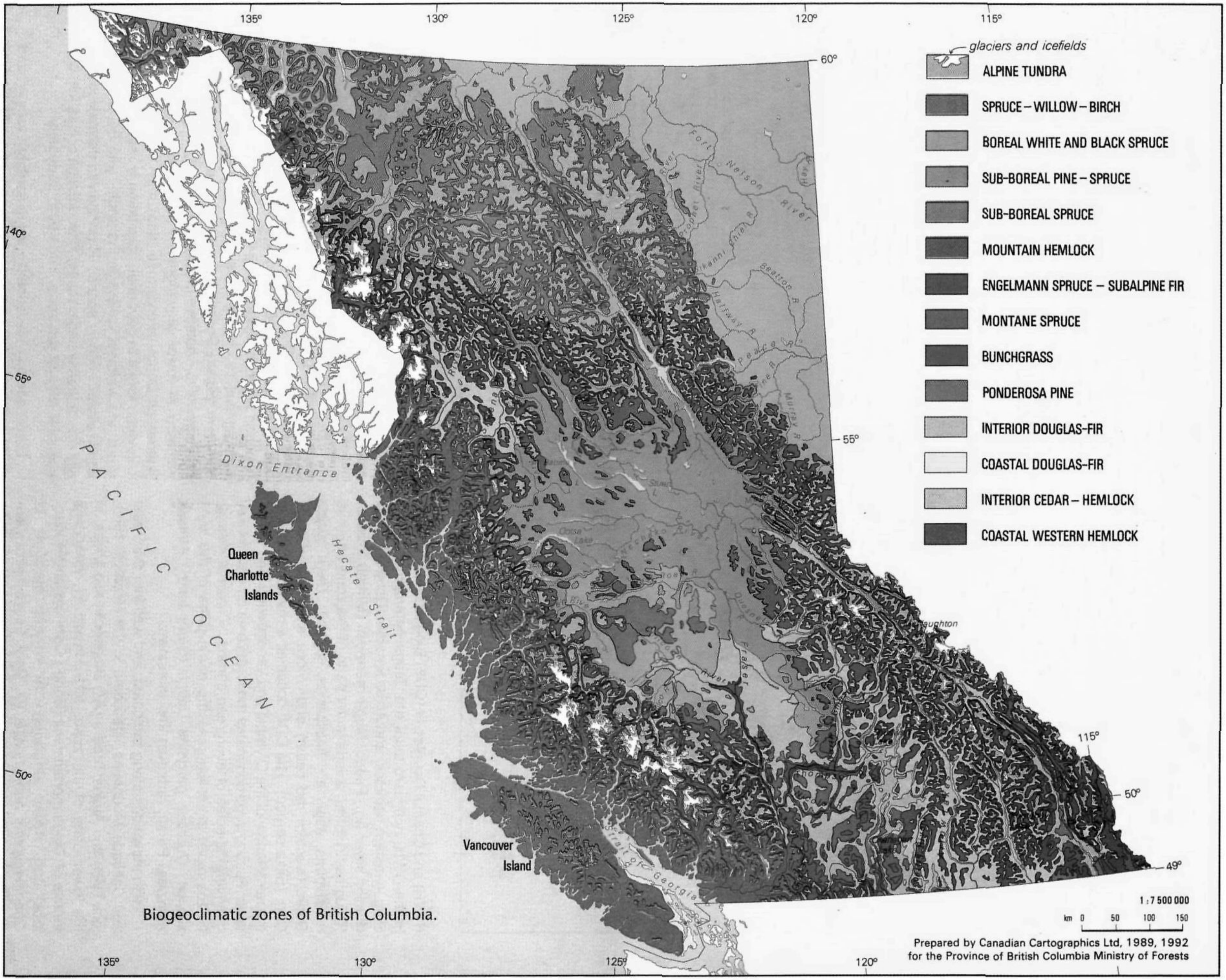
1. Bear Cove Bog, 2. Harbledown Island, 3. Upper Hope Island, 4. Brooks Peninsula, 5. Misty Lake, 6. Barkley Sound, 7. Menzies Bay, 8. Malahat, 9. Saanich Inlet, 10. Rhamnus Lake, 11. Langford Lake, 12. Rithet's Bog, 13. Heal Lake, 14. Surprise, Marion, and Mike Lakes, 15. Fraser River Delta, 16. Pinecrest and Squeah Lakes, 17. Boulton Lake, 18. "Drizzle Pit", 19. Kunghit Island, 20. Argonaut Hill, 21. West Side Pond, 22. Anthony Island, 23. Kelowna Bog, 24. Richter Marsh, 25. Finney Lake, 26. Phair Lake, 27. Chilhil Lake, 28. Fishblue Lake, 29. Horseshoe Lake, 30. "Pemberton Hill" Lake, 31. Dwarf Birch Lake, 32. Pantage Lake, 33. Dunbar Valley, 34. "Bluebird" Lake, 35. Lower Little Slocan Lake, 36. Tonquin Pass, 37. Elk River Valley, 38. Lake O'Hara and Opabin Lake, 39. Mt. Hayes, 40. Seeley Lake, 41. Susie Lake, 42. Waterdevil Lake, 43. Atlin, 44. Kettlehole Pond, 45. Fiddler's Pond, 46. Snowshoe Lake, 47. Lac Ciel Blanc.

(CWH) and Coastal Douglas-fir (CDF) Biogeoclimatic zones. In the CWH, dominant trees are *Tsuga heterophylla* (Raf.) Sarg. (western hemlock) and *Abies amabilis* (Dougl.) Forbes (Pacific silver fir). *Pseudotsuga menziesii* (Mirbel) Franco. (Douglas-fir) forms stands in dry parts of the zone whereas moist parts, especially floodplains, support *Thuja plicata* Donn. (western red cedar) and *Picea sitchensis* (Bong.) Carr. (Sitka spruce). The CDF occupies a restricted area in the rainshadow of the Olympic and Vancouver Island Mountains. *Pseudotsuga* dominates the forest over an understorey of several species of evergreen shrubs. *T. plicata* characterizes moist sites, whereas the driest parts of the zone support *Quercus garryana* Dougl. (Garry oak), *Arbutus menziesii* Pursh. (arbutus) and meadows.

High elevations along the coast, and well into the Coast and Cascade Mountains, are home to the Mountain Hemlock (MH) and Alpine Tundra (AT) Biogeoclimatic zones. In the lower parts of the zone, MH consists of continuous forests of *Tsuga mertensiana* (Bong.) Carr. (mountain hemlock) and *Abies amabilis* with varying amounts of *Chamaecyparis nootkatensis* (D. Don) Spach (yellow cedar). In the upper part of the zone, where snow remains well into the growing season, forests give way to parkland. Sedge and mountain heather communities occur where trees are absent. AT occurs throughout the province wherever severe mountain climate precludes tree growth. Dwarf shrubs, herbs, mosses and lichens predominate in this zone.

Arid valley bottoms and slopes of the southern third of the province support Bunchgrass (BG) and Ponderosa Pine (PP) Biogeoclimatic zones. BG grassland-steppe vegetation occupies the driest and hottest valley bottoms. Today the zone is much disturbed by livestock grazing and intensive agriculture. In little disturbed settings, *Agropyrum spicatum* (Pursh) Scribn. & Smith (bluebunch wheatgrass) predominates. *Artemisia tridentata* Nutt. (big sagebrush) is common at lower elevations. *Pseudotsuga* and *Pinus ponderosa* Dougl. (Ponderosa pine) may occur in draws. This open forest to savannah vegetation is restricted to the driest and warmest valleys in the south, with BG at elevations below it. Widely spaced *P. ponderosa* dominates usually over a grassy understorey. *Pseudotsuga* occurs in moist and cool sites of the zone. Fires burn frequently.

Lower and mid-elevation slopes of southern valleys, and wide expanses of the interior plateau are characterized by the Interior Douglas-fir (IDF) Biogeoclimatic zone. *Pseudotsuga* dominates this zone and *Pinus contorta* Dougl.



Biogeoclimatic zones of British Columbia.

Prepared by Canadian Cartographics Ltd, 1989, 1992
for the Province of British Columbia Ministry of Forests

FIGURE 2. The biogeoclimatic zones of British Columbia (adapted from Meidinger and Pojar, 1991).

Les zones biogéoclimatiques de la Colombie-Britannique (adapté de Meidinger et Pojar, 1991).

(lodgepole pine) is an important post-fire successional species. Characteristic shrubs include *Shepherdia canadensis* (L.) Nutt. (soapberry) and *Arctostaphylos uva-ursi* (L.) Spreng. (bearberry). *Calamagrostis rubescens* Buckl. (pinegrass) and other grasses also grow under the trees.

Mid- to high elevations of the southern interior mountains are covered by Montane Spruce (MS) and Engelmann Spruce-Subalpine fir (ESSF) Biogeoclimatic zones respectively. MS occurs only in the southern half of the province between forests on lower slopes and ESSF stands at higher elevations. *Picea engelmannii* Parry (Engelmann spruce), its hybrid with *Picea glauca* (Moench) Voss (white spruce), and *Abies lasiocarpa* (Hook.) Nutt. (subalpine fir) are dominant. Post-fire successional patches of *Pinus contorta* occur widely and *Populus tremuloides* Michx. (trembling aspen) plays a notable role. *Pseudotsuga* enters the lower and southern sectors of this zone.

The ESSF occupies the uppermost forested elevations throughout the southern two thirds of the province. In the closed forest of the lower part of the ESSF zone *Picea engelmannii, Abies lasiocarpa* and *Pinus contorta* predominate. In the upper sections of the zone, parkland patches contain meadow, heath and grassland. The shrub stratum is often well developed in the forests, with abundant *Rhododendron albiflorum* Hook. (white-flowered rhododendron) and *Menziesia ferruginea* Smith. (false azalea).

Moist, relatively mild valley bottoms and mid-slopes of the southern interior mountain ranges support the Interior Cedar-Hemlock Biogeoclimatic zone (ICH). The characteristic species are *Tsuga heterophylla* and *Thuja plicata*, but *Picea* hybrids and *Abies lasiocarpa* are common. *Pseudotsuga* and *P. contorta* favour dry sites.

Ecosystems related to the northern boreal forest predominate in the north half of British Columbia, and extend southward in the Interior Plateau. The Sub-boreal Pine-Spruce (SBPS) Biogeoclimatic zone is the southernmost of these, occupying a small area in south central British Columbia (Fig. 2). Fire-induced even-aged *P. contorta* stands predominate, but *Picea glauca* occurs in stable locations. The sparse understorey consists mainly of lichens and mosses with patches of *Arctostaphylos uva-ursi* and *Calamagrostis rubescens.*

The Sub-Boreal Spruce Zone (SBS) covers a large area on the Interior Plateau north of SBPS (Fig. 2). *Picea* hybrids and *Abies lasiocarpa* are dominant trees. Numerous fires encourage *P. contorta* in drier parts of the zone. Wetlands are particularly widespread.

Spruce-Willow-Birch (SWB) and Boreal White and Black Spruce (BWBS) zones cover much of the northern third of the province, except high elevations where AT occurs. BWBS is a westward extension of the Canadian boreal conifer forest onto the rolling terrain of northeast British Columbia. A mosaic of *Picea mariana* (Mill.) BSP. (black spruce) bogs, trembling aspen and white spruce stands is characteristic. Repeated fires have encouraged widespread successional stands of *P. contorta* and aspen.

SWB, a subalpine vegetation type, occupies mountainous terrain in the north below AT but above BWBS (Fig. 2). It consists mainly of open forests of *P. glauca* and *A. lasiocarpa* at lower elevations and deciduous scrub birch and willow at higher elevations. A mosaic of scrub, grass and wetland communities occurs below a band of trees in high wide valleys where cold air collects.

VEGETATION AND CLIMATE HISTORY

Previous concepts

Hansen (1947) pioneered paleoecological studies in British Columbia. Widely spaced sampling of peat cores, few identified taxa, and lack of radiocarbon dates limits the value of his results today. Nevertheless Mathewes (1985), in his brief review of Hansen's interpretations, noted that even this pioneering work suggested a warm dry climate in the earlier part of the Holocene followed by increasing moisture and cooling.

Heusser (1960) provided a relatively modern framework with a few radiocarbon dates for coastal British Columbia and adjacent regions. He recognized Late-glacial, Early Postglacial, Hypsithermal and Late Postglacial intervals. The Late-glacial was cooler or colder than today. Heusser viewed the Early Postglacial as being diachronous and lasting about 2000 years during the early Holocene. Heusser interpreted the climate as cool and moist but warmer than the Late-glacial. Heusser's Hypsithermal, which included the 6000 BP mark, spanned the middle of the Holocene and was warmer than today. He recognized drier and moister stages and strongly humid conditions near the end of the interval, coupled with cooling (Heusser, 1960:185). In the Late Postglacial cooler and moister climate returned, marked not only by changes in forest dominants, but changes in peatland character indicated by increases in *Sphagnum* and Ericaceae.

According to Heusser's (1960) interpretation, therefore, the 6000 BP mark fell into a climatic interval warmer than today, soon followed by cooling and increased moisture. Whether it was wetter, drier or the same as today's climate remained unclear.

I (Hebda, 1982b) attempted the next regional synthesis, focusing on southern interior grasslands including those in adjacent United States. Pre-Holocene climate was cold to cool and, toward the end, moist. Because grasslands and sagelands were at their maximum between 10 000 and 8000 BP, I interpreted the climate east of the Coast and Cascade Mountains to have been substantially warmer and drier than today. The middle Holocene from 8000 to 4500 BP, I interpreted as warmer than the present but moister than the early Holocene. The last 4500 years were cool and moist in comparison to the middle and early Holocene. In this region 6000 BP was warmer than today and relatively moist.

Mathewes (1985:418-419) provided the first comprehensive synthesis for the coast and interior of southern British Columbia. He suggested pre-12 000 BP climates may have been colder and drier than today and were followed by cool and moist climate to 10 500 BP. Sudden warming occurred at about 10 500 BP on the south coast, followed by early Holocene "xerothermic" (=dry and warm) climate warmer and drier than the present both on the coast and in the interior. AMS pollen dates now suggest that warming on the coast, as indicated by the regional *Pseudotsuga* pollen rise, probably occurred closer to 10 000 BP (Brown *et al.*, 1989). Peak xerothermic climate ended 7500-7000 BP. The middle Holocene encompassed gradual cooling and increased moisture, indicated by rising lake levels, forest encroachment and expanding ranges of moisture-requiring trees. Relatively modern conditions developed 4500-3000 BP, although some areas may have become cooler and wetter than today as indicated by Neoglacial glacier advances (Mathewes, 1985:419). Thus according to Mathewes (1985), 6000 BP fell into a time of transition from warm-dry to modern or even cool-moist climate, following a xerothermic episode.

The advent of pollen-climate transfer functions, (Mathewes and Heusser, 1981; Heusser *et al.*, 1985) brought a quantitative perspective to climate history for the coast of northwest North America. In general the quantitative climatic trends parallel the qualitative ones outlined previously. Estimates suggest that early Holocene mean July temperatures were 2-4C° greater than the rest of the Holocene with the difference greatest in southern Alaska (4C°) and least in western Washington 1-2C°. Mean annual precipitation was much lower too, about 600 mm less in southern B.C. compared to 900-1000 mm less in Alaska. However, cooler and wetter climate (compared to the early Holocene) developed over a longer interval in southern Alaska (7000-3500 BP) than in Washington and B.C. (7500-6000). Trends to cooler and moister climate appear more or less in phase on south coast sites. In Alaska, most of the cooling occurs before 5000 BP, whereas most of the increase in precipitation occurs between 5000 and 3500 BP.

According to transfer function reconstructions, the 6000 BP horizon on the south coast of B.C. followed a major episode of cooling, and occurred during a climate similar to the present. On the north coast major climatic adjustments had just begun at 6000 BP. These results provide the first clear indications that northern British Columbia climate may have changed at different times than climate of southern British Columbia.

Several syntheses (Heusser, 1985; Mehringer, 1985; and Barnosky *et al.*, 1987) have treated regions adjacent to British Columbia, sometimes including sites from the province. Of these Barnosky *et al.* (1987) provide the most recent and comprehensive perspective on climate for the Holocene up to 6000 BP. In the U.S. northwest and Alaska early Holocene summers were relatively warm and dry, although the time of peak drought varied from region to region and with altitude. The warm dry interval lasted for as little as 2000 years in some Columbia Basin sites, but more usually for 3000-4000 years between about 10 500 and 6000 BP, observations consistent with the interpretations for southern B.C. The montane sites in Idaho, Montana and Wyoming seemed to get warm and dry later and remained so, well into the late Holocene. Thus the 6000 BP horizon fell squarely into a warm and dry climatic episode.

According to these previous studies, therefore, the 6000 BP horizon falls into a transition from warmer and drier-than-present climate of the early Holocene to a climate similar to, or perhaps moister and cooler, than today. This pattern varied throughout the region with apparent delayed onset of cooling northward and possibly eastward (at least in the adjacent U.S.). Although climate is recognized to have been much moister at 6000 BP than before, it is not clear whether the temperature was warmer, the same as, or cooler than today. In this context I examine the pollen, vegetation, climatic and other records of British Columbia's regions.

Regional vegetation and climate histories

I approach the vegetation and climate history of the province regionally because of geographic isolation and marked differences in regional climates, vegetation, and history and intensity of study. For the purpose of this discussion, the B.C. coast is divided into Vancouver Island, Fraser Valley and Lower Fraser Canyon, and Queen Charlotte Islands. Interior B.C. is divided into Southern Interior Plateau, Central and Northern Interior Plateau, Columbia Mountains and Southern Rockies, and northern British Columbia (Fig. 1).

Detailed pollen data from two new sites, and summaries from several of my unpublished sites are included in this treatment. Samples were collected and prepared according to conventional techniques (Hebda, 1983). Zone boundaries were established by inspection. Vegetation and climate were constructed using previous studies (summarized herein), modern pollen spectra (Hebda and Allen, 1993 and references therein) and treatments of ecological requirements of B.C. species such as Krajina *et al.* (1982). Where authors used Mazama ash for a zone boundary (*e.g.* Mathewes, 1973; Mathewes and King, 1989), its age has been standardized to 6800 BP (Bacon, 1983).

VANCOUVER ISLAND

Vancouver Island is characterized by a mild, moist climate which supports cool temperate conifer rainforests of the CWH and slightly warmer and drier CDF forests in the rain shadow along the southeast coast. MH forests predominate on upper slopes of most high mountains with a few patches of AT at highest elevations in the centre of the island.

Vancouver Island, despite being a small area, is relatively well sampled, especially at north and south ends (C. Heusser, 1960; Hebda, 1983; L. Heusser, 1983; Hebda, 1984; Hebda, in press; Walker, 1988; Allen and Hebda, 1993). My students and I have undertaken detailed studies on the south end of the island and the results at 6000 BP for some of these are included in this paper (Fig. 3).

The regional sequence begins with *Pinus contorta*-dominated communities before 13 000 BP under a cool to cold and possibly dry climate (Hebda, 1983; Hebda, in press). In

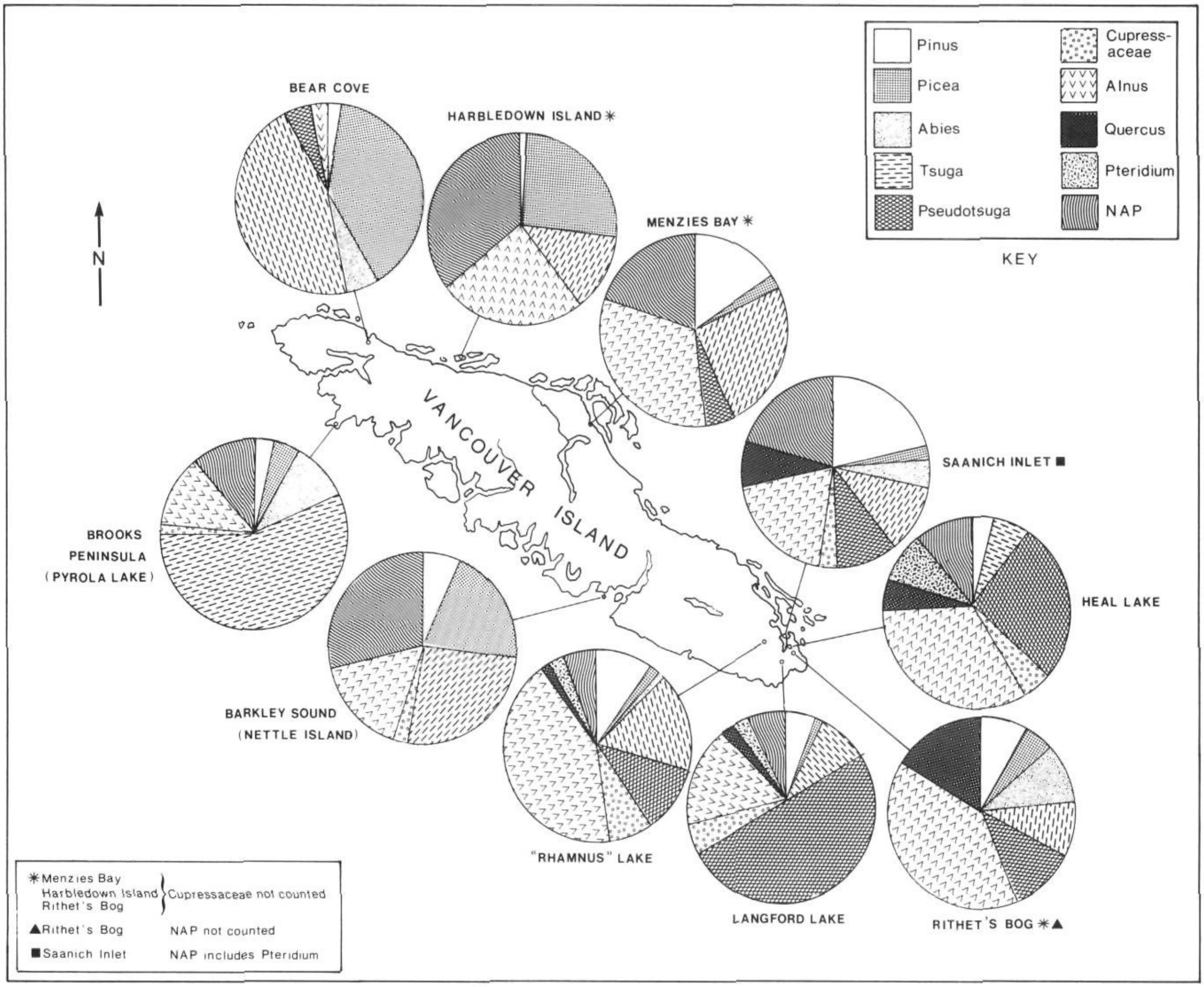


FIGURE 3. Pollen and spore spectra of the 6000 BP horizon from selected sites on Vancouver Island, British Columbia. Used with permission of the Research Branch, Ministry of Forests, Province of British Columbia.

Spectres des pollens et des spores de l'horizon de 6000 ans BP établis à partir de quelques sites de l'île de Vancouver, en Colombie-Britannique. Autorisation de Research Branch, Ministry of Forests, Colombie-Britannique.

the north and west, a brief interval of mixed conifer forest under cool moist climate follows before 10 000 BP. Mathewes (1993) links this with Younger Dryas cooling. Early Holocene (between 10 000 and 9000 BP) warming is recognized with the arrival and expansion of *Pseudotsuga* throughout the region, though its appearance is later and less marked in the north. Indications of increased moisture and possibly cooling begin in the middle Holocene with increased *Tsuga heterophylla* and later Cupressaceae (*Thuja plicata*) pollen values (Heusser, 1985). The trend to increased moisture begins before 6000 BP (Hebda, 1983; L. Heusser, 1983; Heusser, 1960) though Heusser (1985: 155) considers warmer summer-dry climate to have persisted until 3000-2000 BP on the basis of high *Quercus garryana* pollen values.

In Heusser's (1960: Table 6) early summary of 7 sites for Vancouver and adjacent islands he placed the 6000 BP horizon squarely in the Hypsithermal during which, according to him, regional mean annual temperatures were higher than today. Chronological control on south Vancouver Island was available for the horizon, because by that time an age for Mazama Ash, now dated at 6800 BP (Bacon, 1983), had been established. All the major species were on the island, and the region was largely forested.

Forest composition was not, however, the same as later in the Holocene. Perhaps the most important feature was that *Tsuga heterophylla* played a much less important role in the forests than today. We know now that Cupressaceae (mainly *Thuja plicata*) were much less prominent (Hebda and Mathewes, 1984). On the other hand *Pseudotsuga menziesii*, *Alnus*, and *Lysichitum americanum* Hultén & St. John (skunk cabbage) were more abundant. Heusser (1960) noted for some sites that *Lysichitum* was characteristic of middle Holocene peatlands, being later replaced by heaths and *Sphagnum* spp.

More comprehensive studies during the last 15 years have refined these interpretations substantially, through more tightly controlled chronologies, by the inclusion of

Cupressaceae pollen in profiles and by the study of sites from a wider area, especially the west side of the island.

On the north end of Vancouver Island, 6000 BP vegetation, and presumably climate, were very different than today. At Bear Cove Bog near Port Hardy (Fig. 1, #1) 6000 BP forests were dominated by *T. heterophylla* and *Picea sitchensis* (Bear Cove Zone 4A, Hebda, 1983) (see Fig. 3 for pollen percentages). *Pseudotsuga*, *Alnus*, and *Pteridium aquilinum* (L.) Kuhn (bracken) had declined from the previous zone. This change indicated a moister climate than in the early Holocene. Changes in peat stratigraphy also suggest increasing moisture, as predominantly dense humic peat gave way to sedge peat or woody *Sphagnum* peat about 6000 BP. Only well after 6000 BP did the forests take on a modern look, dominated by western red cedar and western hemlock. From these characteristics, I concluded that the climate at 6000 BP was warmer and slightly drier than today.

Similar hemlock-spruce forests grew to the south on Harbledown Island (Fig. 1, #2) (Heusser, 1960). Heusser's (1960) Upper Hope Island (Fig. 1, #3) sequence north of Port Hardy is difficult to interpret because of local overrepresentation of Cyperaceae and *Lysichitum* pollen, but there too, western hemlock and spruce were dominant forest elements although lodgepole pine may have played a role too.

A series of three cores from lowland and upland sites of the Brooks Peninsula (Fig. 1, #4) provides insight into the vegetation and climate on the mild and very moist northwest coast of Vancouver Island (Hebda, 1984: Hebda, in press). Brooks Peninsula is located within the CWH zone.

The 6000 BP horizon falls within a long interval, 9000-2500 BP, of relatively stable vegetation and climate. *T. heterophylla* forests predominated with *Abies* and Cupressaceae as major elements. Earlier in the Holocene *Picea* had been more abundant. *Thuja* and *Chamaecyparis* (Cupressaceae) became co-dominant with *T. heterophylla* after 2500 BP. I interpret the 6000 BP climate as very moist and relatively warm, certainly moister than the earliest Holocene when *Picea sitchensis* forests with occasional *Pseudotsuga* trees occupied mesic sites.

Walker (1988: 48) examined chironomid assemblages at Misty Lake (Fig. 1, #5) on north Vancouver Island and concluded that "Holocene faunal changes ... illustrate few trends". He noted that the abrupt decline of the cool water profundal species which occurred *ca.* 5000 BP might have been the result of gradual infilling. Walker (1988) provided some general pollen data from analyses by R. Mathewes. As at Bear Cove Bog to the north, western hemlock and spruce prevail at 6000 BP suggesting a wetter and cooler climate than in the Fraser Valley. He notes "gradual Holocene climatic deterioration and paludification ... above 6.0 m" about 7000 BP. This trend was well under way by 6000 BP.

My unpublished results from Barkley Sound (Fig. 1, #6) on the central west coast of Vancouver Island reveal vegetation and climate at 6000 BP (Fig. 3). Local geomorphic history complicates interpretation of climate because it includes a brief marine inundation. Nevertheless the arboreal component is dominated by *T. heterophylla*, *P. sitchensis* and *Alnus* pollen. Locally growing *Lysichitum* contributes *ca.* 25% of the pollen. The arboreal assemblage appears consistent with those on the north end of the island. However, because this site is, and was near the shore, the high *Picea* pollen values could be attributed to the shoreline spruce zone, a result of salt-spray influence (Krajina *et al.*, 1982).

At Menzies Bay (Fig. 1, #7), near today's CDF limit on east Vancouver Island, *P. sitchensis* played only a minor role in early and mid Holocene vegetation (Heusser, 1960). *T. heterophylla* was by this time a major element of the vegetation and *Pseudotsuga* occurred infrequently. Relatively dry climate may have limited spruce in this area because it thrives best on hygric rich sites. In any case 6000 BP vegetation and climate of east central Vancouver Island were different from those of the west coast and north.

Further south the warm dry climate of southeast Vancouver Island supports CDF vegetation and also exhibits a history markedly different from cool and moist parts of the island. In this region rainfall is sufficiently low that around Victoria, *Quercus garryana* woodlands and meadows replace the typical dense conifer forests of the rest of Vancouver Island.

Calvin Heusser (1985) summarized his early work at Malahat and Linda Heusser's (1983) marine core from Saanich Inlet (Fig. 1, #8, 9) to provide a general framework. Communities of *Pinus contorta* and perhaps *Pinus monticola* Dougl. *ex* Dougl. *in* Lamb (western white pine), containing *Alnus*, were commonplace in the Late-glacial. The early Holocene is characterized by high values of *Pinus*, *Pseudotsuga*, *Alnus* and Poaceae pollen. The arrival of *Quercus* and first increases in Cupressaceae pollen between 8000-7000 BP complete the arboreal assemblage (Heusser, 1983). Oak persisted at high percentages until 3000-2000 BP, after which increases in *T. heterophylla* and Cupressaceae pollen signalled humid and cooler climate.

In the Saanich Inlet core (Heusser, 1983) at 6000 BP, pollen assemblages are characterized by the trees *Quercus*, *Pseudotsuga*, *T. heterophylla* and *Alnus* (Fig. 3). Poaceae pollen is less abundant than in the early Holocene and *Pinus* pollen is sufficiently low to suggest that *P. contorta* was not a major element of the regional vegetation. Exceptionally high values for oak pollen at 6000 BP are particularly telling because they imply nearly continuous oak forest or parkland on the surrounding hilly upland (see Allen, 1995). Oak is generally considered a xerophyte. Heusser (1985) presumably used it as a xeric indicator to suggest warmer-than-present, dry summers at 6000 BP. Oak however grows on moist floodplains (Stein, 1990) and may be limited more by competition with conifers and by cold temperatures rather than precipitation. Because of decreased Poaceae and increasing *T. heterophylla* pollen, I suggest that the climate must have been warmer than today but relatively moist compared to the early Holocene.

Another important feature is that Cupressaceae (assumed to be *Thuja plicata*) pollen begins to increase significantly at 6000 BP suggesting increasing moisture and declining temperatures. This pattern is clearly evident from a core (Rhamnus Lake) west of Shawnigan Lake in the CDF/CWH transition (Fig. 1, #10). Here Allen (1995) records a 6000 BP pollen assemblage where *Alnus*, *Pseudotsuga*, and *Tsuga heterophylla* constitute the dominant pollen types but oak is a minor component (Fig. 3). It is just at 6000 BP that *T. heterophylla* pollen values double and, for the first time, become greater than *Pseudotsuga*. This signals a change in forest composition with *T. heterophylla* becoming an important forest tree at the cost of *Pseudotsuga* which is more drought tolerant.

At Langford Lake (Fig. 1, #11) (Hebda, unpublished) the 6000 BP horizon falls into a relatively long interval lasting from *ca.* 7800 to 1000 BP which I tentatively interpret as being characterized by Douglas-fir - Oak woodland. The principal pollen types include *Pseudotsuga*, *Alnus*, Cupressaceae, and *Quercus*. *Quercus* values fluctuate from 0 to more than 10%, generally being much greater than in the last 1,000 years. At about 6000 BP, just after deposition of Mazama Ash, *Quercus* pollen rises from 2-3% to 4-9% suggesting some climatic adjustments (Fig. 3). About this time, *Pseudotsuga* pollen values rise from the 20-30% range to the 30-50% range. Increases are at the expense of *Pinus*. I interpret these changes as the development of more complete forest cover and local sources of arboreal pollen, at the cost of the regional pollen rain of *Pinus contorta*. I interpret the interval just before and including 6000 BP to be one of increasing moisture. A more precise interpretation awaits completion of analysis and production of a pollen diagram.

An unpublished undergraduate thesis from Rithet's Bog (Fig. 1, #12) by Zirul (1967) provides limited insight into the vegetation and climate of a basin in the driest part of the CDF, where *Quercus garryana* stands and meadow communities predominate (Fig. 3). Using Mazama Ash (6800 BP) as a reference level in this undated arboreal pollen diagram, it is evident that *Alnus* pollen predominates, but *Quercus* pollen at 15-20% is also a major element of the tree spectrum. For reference, late Holocene oak values (= modern pollen rain) are less than 1% at this locality. Indeed in Zirul's (1967) diagram *Quercus* pollen is more abundant than *Pseudotsuga* at about 10%. The 6000 BP horizon occurs at the point where *Quercus* is most abundant during postglacial time, suggesting oak woodland or forest surrounded the basin. Soon after this level, *Quercus* declines to between 2 and 5% whereas *Pseudotsuga* and *T. heterophylla* rise, suggesting increased moisture. Unfortunately the absence of NAP counts makes it difficult to assess the nature and extent of non-arboreal communities at Rithet's Bog. Clearly though, the vegetation and presumably climate at the time were very different than today.

Further evidence that the 6000 BP horizon falls into a time of increasing moisture on south Vancouver Island comes from stratigraphic observations at Heal Lake northwest of Victoria (Fig. 1, #13). The sediment sequence at the lake's edge suggests an interval of lowered water levels and little or no organic sediment accumulation in the early Holocene. Beginning just before Mazama Ash deposition, water levels rose sufficiently for dy to accumulate at the lake's edge. After Mazama Ash time (6800 BP), water levels rose at least 2 m and a lake edge bog formed. The precise timing of this rise is currently under study. The 6000 BP horizon falls clearly into a interval of rising water levels.

Continued detailed studies on southern Vancouver Island, especially of macrofossils and the exceptional tree-ring record from Heal Lake (Hebda, 1993), will eventually provide precise data on the nature of the vegetation and climate at 6000 BP. However general features of vegetation and climate are clear and show substantial differences from present conditions. The north end of the island, especially the east coast, supported much more *Picea sitchensis*, whereas in the extreme south, oak forest or savannah predominated, gradually giving way to more coniferous stands, dominated by *Pseudotsuga* then *T. heterophylla* westward. *T. heterophylla* and especially Cupressaceae, both good indicators of very moist climate, were less abundant than today.

At 6000 BP climate was moister than in the early Holocene and became increasingly wetter into the middle and late Holocene. Much of the increase had occurred before 6000 BP, starting before 7000 BP. Climate may have been slightly warmer as well, perhaps by about 1C° mean annual temperature, given the greater role of oak compared to today and the diminished role of western hemlock and cedar.

FRASER VALLEY AND LOWER FRASER CANYON

This region is largely situated in the CWH, with elevations above 900 m supporting MH vegetation and AT only on the highest peaks to the north. Eastward the CWH extends along the Fraser River into the confines of the Fraser Canyon where it meets a narrow tongue of IDF extending at low elevation from the interior of the province.

Studies by Mathewes and others (Mathewes, 1973; Mathewes and Rouse, 1975; Wainman and Mathewes, 1987) provide much insight into the vegetation and climatic history of this region and the 6000 BP horizon. Furthermore, using transfer functions derived from an extensive series of modern spectra, Mathewes and Heusser (1981) generated estimated precipitation and temperature curves for the lower Fraser Valley.

The simplified vegetation sequence from Marion Lake (Fig. 1, #14), which is similar to nearby Surprise Lake (Mathewes, 1973; Mathewes and Heusser, 1981; Wainman and Mathewes, 1987), begins with a shrub-lodgepole pine assemblage (zone ML-1) which gives way to a lodgepole pine assemblage (zone ML-2) suggesting a cool continental climate. Just before the onset of the Holocene, other coniferous taxa and *Alnus* pollen increase in importance (Zone ML-3), generally reflecting cool and moist climates. The sudden appearance of *Pseudotsuga* pollen around 10 000 BP signals warming and drying. *Alnus* and *Pteridium* increase along with *Pseudotsuga*. Transfer function analyses suggest a rise of about 2C° mean July temperature and decline of *ca.* 600-700 mm mean annual precipitation (Mathewes and Heusser, 1981). About 6800 BP (beginning zone ML-4) *Tsuga heterophylla* values rise to reach maximum percentages between 6000-4500 BP. *Pseudotsuga* and *Alnus* values generally decline with the *Tsuga* rise. *Abies amabilis* macrofossils occur conspicuously with the *T. heterophylla* pollen rise, a strong indication that this change is a result of increasing moisture. These early Holocene changes occur in the millennium and a half before the 6000 BP horizon, by which time their effects are well established. With the exception of the anthropogenic *Alnus* pollen increase in the last century and a half, the last 3000 years are characterized by pollen and macrofossil assemblages dominated by *T. heterophylla* and *Thuja*, characteristic of the CWH forests and moderate moist climate of the area today.

Walker and Mathewes (1989) included a brief pollen assemblage summary for Mike Lake (Fig. 1, #14) 4 km south of Marion Lake, and still in the CWH zone. The record is very similar to that at Marion Lake. Following relatively high *Pseudotsuga* pollen percentages in the early Holocene, *T. heterophylla* percentages increase between 8000 and 7000 BP suggesting a shift to the moist climate of the Fraser Valley today. The other major arboreal indicator of moisture, *Thuja*, only rises substantially at about 5600 BP (3.5 m level of core).

Williams and Hebda (1991) reported a record within the Fraser River Delta (Fig. 1, #15) which includes the 6000 BP horizon. They interpreted the sequence largely on the basis of changes in local wetland plant communities. The increasing abundance of arboreal types, comprising *T. heterophylla*, *Picea*, *Pinus* and *Alnus*, at the beginning of zone D23-3 *ca.* 6800 BP is especially notable. The increase was related to a shift from herb- to shrub-dominated wetland vegetation with resulting relative increases in arboreal taxa. A similar change could also be the result of changes in regional vegetation from a predominantly open state to a forested state associated with wetter climate. A significant proportion of the pollen in deltaic sediments arrives in the silt and clay fraction during the annual flood (Hebda, 1977) so the pollen curve shifts could have resulted from vegetation changes well up river. Mathewes and Rouse (1975) reported on two sites, Pinecrest and Squeah Lakes (Fig. 1, #16) adjacent to the Fraser River, just south of the climatically sensitive transition from CWH to IDF. Of the two lakes, Pinecrest was completely analyzed whereas the Squeah Lake record only includes pre-Mazama Ash time. The sequence from both sites resembles that at Marion Lake to the west but includes abundant *Betula* (birch) and higher *Pseudotsuga* values throughout the Holocene, accompanied by less *T. heterophylla*. The early Holocene before 6600 BP also exhibits relatively high Poaceae, *Artemisia* and other NAP types. As in western Fraser Lowland sites, major climatic and vegetation changes occurred just before 6000 BP. A trend to wetter conditions began in the later part of the early Holocene (upper zone PL-2) with increasing *T. heterophylla*, *Abies* and *Betula* pollen and decreases in open habitat taxa such as Poaceae and *Artemisia*.

In summary, Fraser Lowland and Canyon records suggest that the 6000 BP horizon followed climatic adjustments, are involved both cooling and increased mean annual precipitation. Though the pollen assemblages and vegetation at 6000 BP were beginning to resemble modern ones, they were not the same. *T. heterophylla* was particularly more abundant, whereas *Thuja* was much less abundant than today.

QUEEN CHARLOTTE ISLANDS

This forested mountainous archipelago is situated predominantly in CWH with patches of MH at high elevations. Peat bogs are widespread. The cool and moist equable climate is strongly influenced by the surrounding Pacific Ocean. The Queen Charlotte Islands have been studied mainly by Mathewes and colleagues (Mathewes, 1989 and references therein; Quickfall, 1987), supplemented by a recent investigation by Fedje (1993).

Mathewes (1989) reconstructs vegetation (mainly sites from northeast Graham Island, Fig. 1, #17, 18, 20) prior to 9400 BP as lodgepole pine forest with alder, spruce, and mountain hemlock. Thereafter pine declines and spruce and hemlock share dominance of the forest until about 5500 BP. Warner (1984), who studied cores from eastern Graham Island, viewed the interval between 9400 and 7400 BP as a climatic optimum with reduced humidity and relative warmth. He felt that climate continued warm until 5500 BP but moisture increased. During this climatic optimum lakes were small and bog surfaces dried. Traces of Cupressaceae pollen occur in the spruce-hemlock interval but this pollen type increases significantly in the middle and later Holocene along with pine. Mathewes (1989) suggests that increases in these two types may signal local increased bog formation beginning about 5500 BP. Increases in ericaceous pollen and *Sphagnum* spores support this conclusion. Upland forests still contained spruce and western hemlock, but according to Mathewes (1989) the role of pine and Cupressaceae in the forest increases too. At Boulton Lake (Fig. 1, #17) a second rise in Cupressaceae about 3000 BP marks the development of today's western hemlock - western red cedar forests. Warner (1984) interpreted the climate of the last 5500 years as cool, moist and mesothermal like that today.

Quickfall (1987) examined initiation of peat bog growth on the Queen Charlotte Islands and showed that two of three bogs began forming in the middle Holocene (basal radiocarbon dates from "Drizzle Pit" 4320 ± 100 BP (Fig. 1, #18), Kunghit Island 5150 ± 70 BP (Fig. 1, #19). Argonaut Hill bog (Fig. 1, #20) arose about 8000 BP but major peat growth began only about 5000 BP, a time when woody peat is replaced by wood and herb detritus (Quickfall, 1987: Fig. 6). Quickfall noted that as the bogs grew they expanded into forested terrain. At all sites the regional forest at the time of bog development consisted of *Picea sitchensis* and *Tsuga heterophylla*. Cupressaceae pollen, assumed largely to be produced by *Thuja plicata*, was less abundant than present. Quickfall (1987:89) concludes that the middle Holocene events he observed are the result of "...reduced temperatures and/or increased precipitation".

Fedje's (1993) record at West Side Pond (Fig. 1, #21) includes pre-Holocene pioneering shrub-herb vegetation (13 500-12 500 BP) followed by pine woodland with openings (12 500-11 200 BP), then alder and Sitka spruce stands, with notable mountain hemlock (11 200-9900 BP). Fedje (1993) interprets pollen assemblages of alder, Sitka spruce, and western hemlock, presumably the result of mixed forest stands, to reflect warm moist early Holocene (9900-8700 BP) climate. Warmest (xerothermic) climate occurs from 8700-7500 BP when alder and spruce pollen, and presumably stands, are characteristic. Fedje (1993) interprets pollen spectra dominated by western hemlock and alder with some spruce (= hemlock-dominated forest?), from 7500-5000 BP to indicate warm and moist climate. Modern relatively cool and moist climate has developed during the last 5000 years when cedar pollen (= mostly western red cedar) increases to modern values.

My unpublished section, from Anthony Island (Fig. 1, #22) southern Queen Charlottes Islands (summarized here), provides further insight into the vegetation and climate adjacent to and at the 6000 BP mark. The record begins about 13 000 years ago with *Pinus contorta* stands, but these are replaced by *Picea sitchensis* forests by 12 000 BP. *Picea* predominates until 7500 BP, when *Tsuga heterophylla* becomes codominant. Western hemlock-Sitka spruce forests continue on the island through the 6000 BP mark until about 2000 years ago when *Pinus contorta* returns and persists until just before the present. Several major archaeological sites occur on the small island and the pine interval may be related to human disturbance. Western hemlock and spruce predominate today. Cupressaceae play a notable role only during the last 4000 years.

All of these records indicate that on the equable and mild Queen Charlotte Islands the 6000 BP horizon seems to fall into relatively warm and moist period, which followed a warmer and perhaps slightly drier time than today. The change to moist climate begins about 7500 years ago. The 5500-4000 BP interval includes a major shift to cooler and possibly still moister climate associated with bog initiation and expansion as signalled by increased Cupressaceae and pine pollen, and an expanding role for Cupressaceae in the forests. Thus 6000 BP appears to fall into an interval between two periods of change, increased moisture *ca.* 7500 BP and cooling (perhaps further increased moisture) 5500-4000 BP.

SOUTHERN INTERIOR PLATEAU

This region exhibits a diverse physiography, climate and vegetation. The principal physiographic elements include deep steep-sided valleys occupied by rivers and lakes. Some of the valleys are cut to 300 m above sea level. Valleys are surrounded by extensive upland zones, mostly between 1000 m and 2000 m, and several mountain ranges which reach over 2500 m. Consequently vegetation and climatic patterns exhibit sharp changes with elevation resulting in relatively narrow but wide-ranging lowland vegetation zones which fringe large patches of upland zones on the rolling upland plateau.

A typical biogeoclimatic zone (see "Ecosystems and Vegetation" for abbreviations) sequence in the south would include open BG communities in valley bottoms with PP savannah on the lower slopes immediately above (see Research Branch, 1988). IDF forests occur above the PP and spread onto lower elevations of the rolling plateau. MS forests give way to ESSF forests at high elevations, and AT covers upper slopes on the highest peaks. At the eastern limits of the region, moist ICH forests occur on the valley bottoms or adjacent to IDF. The importance of this pattern is that many sites have been sensitive to precipitation and temperature changes because major vegetation boundaries and climatically-controlled species limits were never far away.

Several published and unpublished records reveal the vegetation and climatic history, though the number of sites investigated is far too small for such a complex terrain. In this account I include summaries of previous studies with emphasis on 6000 BP, describe a new site, "Pemberton Hill Lake", and briefly mention three unpublished records.

My summary (Hebda, 1982b) of southern B.C. and adjacent grassland sites provides a framework for the vegetation history of the region (Fig. 4). My original analysis emphasized curves of Poaceae and *Artemisia* pollen. Pioneering grasslands (non-arboreal communities) occurred in deglaciated sites as early as 13 000 BP under a cold climate (Hebda, 1982a). Forests developed between 12 000 and 10 000 BP but valley bottom grasslands containing *Artemisia* and Poaceae persisted. I interpreted the climate as cool and moist. In the hot, dry early Holocene (10 000-8000 BP) grasslands and sagelands reached their maximum extent, up to 1300 m above sea level, and probably connected valley-bottom to mountain-top non-arboreal communities.

From 8000 to 4500 BP the grassland area shrank as shown by decreases in percentages of Poaceae and *Artemisia* pollen. The decline was well under way by 6000 BP, but at most sites NAP values were still higher than today. Forest species, especially *Pseudotsuga*, expanded. I interpreted climate to have been moist but still warmer than present. Between 4500 and 3000 BP grasslands reached their minimum extent, being restricted to valley bottoms. The climate was relatively cool and moist. Several pollen curves suggest that grasslands have expanded slightly during the last 3000 years even before major disturbance and clearing by European settlers in the 1800's.

Alley (1976) published a record from Kelowna Bog (Fig. 1, #23) spanning about 9000 years from the PP zone of the central Okanagan Valley. According to him early *Pinus* forests with *Picea* stands colonized valley sides. By 8400 BP Poaceae and *Artemisia* communities expanded under a hot and dry Hypsithermal climate. Wind eroded sparsely vegetated valley bottoms. At 6800 BP moist and cool climates returned and trees (*Betula*, *Picea*, *Pinus*) became more abundant.

One of three major *Betula* pollen peaks occurs at the 6000 BP level (1.2 m in the core), associated with relatively abundant *Alnus* and *Corylus* (hazelnut). Alley (1976) interpreted these as responses to locally increased water table caused by augmented local and upland water supply under a climate slightly cooler and moister than the present. He argued that these changes relate to Neoglacial advances. Alternatively, these single sample peaks, he acknowledges, might be related to fire, rather than climatic causes. Alley implies that the birch pollen is derived from *Betula papyrifera* Marsh (paper birch), whereas local stands of *Betula occidentalis* Hook. (water birch) or *Betula glandulosa* Michx. (dwarf birch) might be involved. Thus increases might suggest drying of the bog surface rather than increased moisture. Clearly though, shifts from *Artemisia* — Poaceae to more trees at 6800 BP place the 6000 BP horizon in a time of increasing moisture, perhaps to levels similar to present.

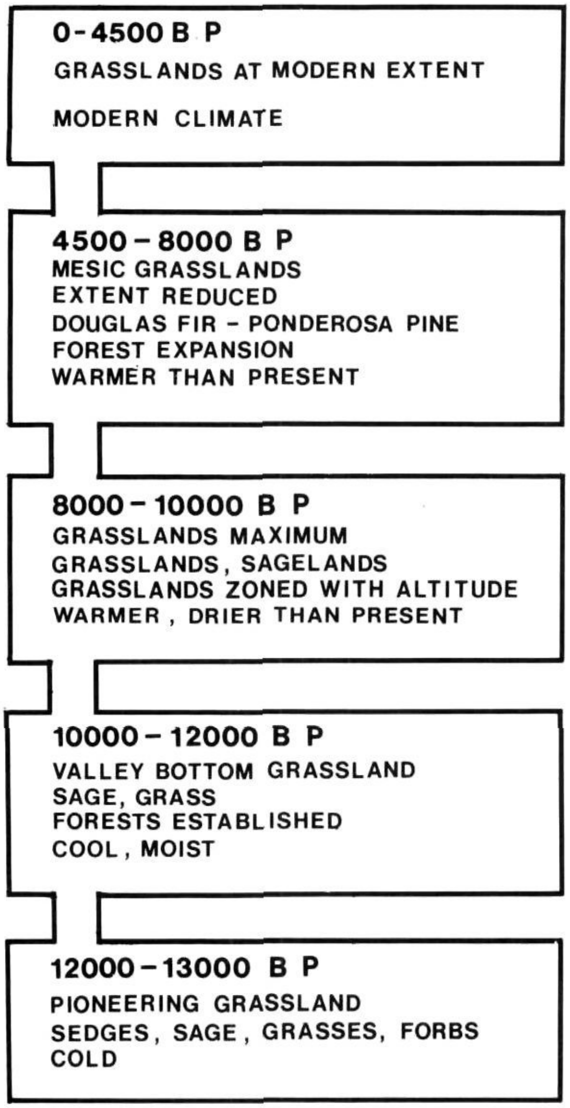


FIGURE 4. Phases of grassland vegetation history and climatic interpretation for the south interior of British Columbia and adjacent regions, modified from Hebda (1982b).

Évolution des différentes phases de prairies et interprétation climatique de la partie intérieure méridionale de la Colombie-Britannique et des régions adjacentes (modifié de Hebda, 1982b).

Cawker (1983) included an undated diagram from Richter Marsh (Fig. 1, #24), which he correlated with Alley's (1976) zones, as part of study of fire and vegetation change of southern interior B.C. This record is significant because it represents the most xeric of all B.C. vegetation zones, the BG zone. Assuming Cawker's correlation with Alley's (1976) zones is correct, then the early Holocene was very warm and dry as reflected by high Poaceae and *Artemisia* pollen values. The highest charcoal values of the sequence occur within this hot, dry interval. The hot, dry state persists until just after 6800 BP when increases in several coniferous pollen types, especially *Picea*, signal "cooler and moister" climate according to Cawker (1983: 1135). He notes a return to arid conditions following the cool moist phase in the middle Holocene. Renewed arid climate seems to have persisted almost to the present. According to Cawker's interpretation of this sequence, the 6000 BP horizon falls into a relatively cool moist period. Because this record comes from a potentially discontinuous sedimentary sequence with no radiocarbon dates or Mazama ash, and has widely spaced sample intervals, a clearer understanding of BG zone history awaits a more comprehensive study.

Two studies from neighbouring areas within the IDF zone (Hebda, 1982a; Mathewes and King, 1989) provide insight into early Holocene and 6000 BP environments and climates at the western margin of the southern Interior Plateau. At Finney Lake (Fig. 1, #25) in the Hat Creek Valley late-glacial cool-climate non-arboreal and *Populus* vegetation assemblages were followed by hot and arid *Artemisia* steppe from 10 500-8500 BP (Hebda, 1982a). At the beginning of the hot dry episode Finney Lake contained little water, depositing marl or marly clays even in the deepest portions. From 8500-4000 BP forest cover increased with *Pinus*, *Betula*, *Pseudotsuga* and shrubby *Alnus* more abundant. NAP remained relatively high suggesting that valley bottoms remained open. During this interval lake gyttja rather than marl accumulated. Climate was probably warmer than present but moister than during the preceding interval. Only in the last 4000 years, under modern climate, did the lower forest (*Pinus* and *Pseudotsuga*) limit descend below the elevation of Finney Lake.

Mathewes and King (1989) showed that pre-6800 climate was very dry in the middle Fraser Canyon. One of two lakes (Phair Lake, Fig. 1, #26) in the driest climate and did not exist prior to 7000 BP. The other (Chilhil Lake, Fig. 1, #27) seems to have developed just before 8000 BP. NAP types indicating open or "drawdown" communities occur most abundantly before 6800 BP at these lakes, and at two lakes (Fishblue Lake, Horseshoe Lake; Fig. 1,#28,29) from a moister climatic regime nearby. From 6800 BP to the present trees played a more important role in the vegetation implying a moister climate than before. At Chilhil Lake there is a shift from grassland to transitional forest-parkland *ca.* 7000 BP. At Horseshoe and Fishblue Lakes *Pseudotsuga*, *Betula* and *Tsuga heterophylla* pollen become more abundant after 6800 BP reflecting the development of modern forests (Mathewes and King, 1989).

The sediment and pollen records of IDF sites of the west edge of the southern Interior Plateau clearly place 6000 BP into a significantly moister climatic regime than the early Holocene xerothermic interval (Mathewes and King, 1989). Most of the climate change had occurred earlier, although adjustments, such as the sharp *Pinus* pollen rise at Chilhil Lake and forest expansion at Finney Lake at about 4000 BP, continued. The climate was probably as moist as today, but might have been at least slightly warmer.

Pemberton Hill Lake

Pemberton Hill Lake (an informal name assigned by R. Hebda) is located at 1020 m elevation in the IDF zone in a small valley 30 km east of Kamloops B.C. in the mid- to eastern part of the southern Interior Plateau (Fig. 1, #30; Fig. 5). Open BG communities occur only 4 km to the south in the South Thompson River valley (Fig. 5).

This 250 m diameter lake reaches a maximum depth of 3.5 m, although most of it is only 2.5 m deep. Most of the lake is surrounded by *Typha latifolia* L. (common cattail) stands. *Pseudotsuga menziesii* dominates the surrounding forest, with scattered *Betula papyrifera*, *Picea engelmannii* and *Pinus contorta*.

The core consists largely of greenish brown gyttja which extends from the surface to 5.90 m. One layer of volcanic ash occurs at 3.35-3.40 m with pockets extending to 3.50 m. Another ash layer with a sharp upper boundary occurs at 4.58-4.60 m with traces of ash extending as deep as 4.70 m, where there is a 5 cm-thick, fine-grained ash unit. Post-depositional break up and sinking of Mazama ash into soft lake sediment may be the cause of this double ash feature (see Anderson *et al.*, 1984). Marly light and dark laminae occur throughout the gyttja from 4.75-5.90 m. Shells appear throughout the sequence but are most abundant near the base. Shell-rich carbonate gyttja grading to marl, which is then interbedded with silty clay, spans 5.90-6.15 m. From 6.15-6.35 blue grey silt dominates. Radiocarbon dates are summarized in Table I.

a) Pollen zones

The earliest zone (PHL-1: 6.30-6.00 m: *Pinus*) spans *ca.* 10 500-9800 BP, and is dominated overwhelmingly by *Pinus* pollen mostly of the diploxylon type (= *Pinus contorta*) (Fig. 6). This unit is followed by a diverse zone (PHL-2: 6.00-4.75 m: *Betula-Pinus*-NAP) extending from 9800 BP to 7000 BP in which *Pinus* decreases below 60% in the first half of the zone and as low as 30% in the latter half. *Populus*, Cupressaceae and *Shepherdia* pollen types are abundant at the beginning of the zone, reaching their highest values in the core. This zone includes a sudden *Alnus* increase from almost 0 to 13% at the start. At about 9500 BP *Betula* reaches 30-40% and Poaceae rise sharply and remain high. In this zone *Artemisia* and *Equisetum* (horsetail) are also relatively abundant.

Zone PHL-3 (4.75-3.50 m: *Betula-Pseudotsuga*-NAP) extends from about 7000 BP to 4000 BP. It begins with a major increase in *Pseudotsuga* pollen (1-15%) and decline in *Betula*, while Poaceae and *Artemisia* remain at relatively high levels. The zone ends at 3.50 m with a decrease in *Pseudotsuga* preceded by a sharp increase in *Pinus* from 40% to more than 60%. *Betula*, Poaceae and *Artemisia* all decline at or near the end of the zone.

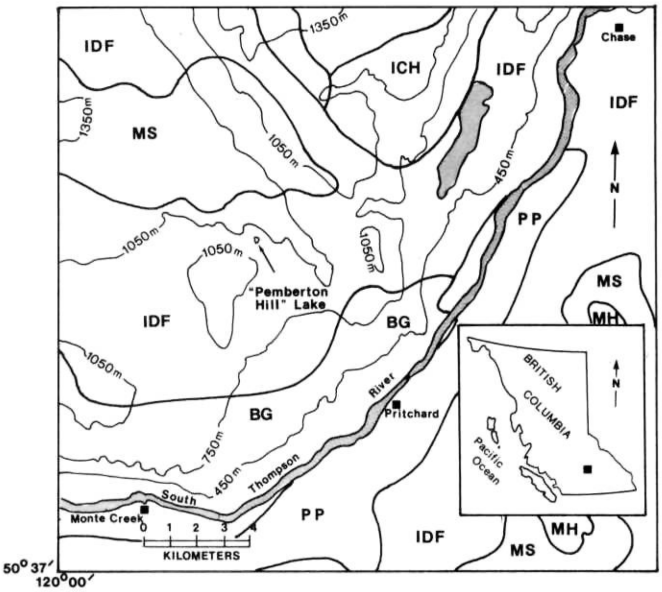


FIGURE 5. Location and vegetation zones of the "Pemberton Hill" study site and surrounding area.

Localisation et zones de végétation du site de « Pemberton Hill » et des environs.

TABLE I

Radiocarbon dates from "Pemberton Hill" Lake and "Bluebird" Lake, British Columbia (all dates adjusted for δ13)

Date	Lab number	Description
Pemberton Hill Lake		
9750 ± 190	WAT-916	592-600 cm of core, silty gyttja
7600 ± 130	WAT-923	520-530 cm of core, gyttja
5100 ± 80	Beta-70915	410-420 cm of core, gyttja
2700 ± 90	Beta-70914	260-270 cm of core, gyttja
Bluebird Lake		
9560 ± 130	WAT-819	490-500 cm of core, gyttja
8570 ± 100	WAT-820	430-440 cm of core, marly gyttja
2420 ± 160	SFU-126	160 cm in core, *Betula* wood

In the most recent zone (PHL-4: 3.50-0.00 m: *Pinus-Pseudotsuga-Picea*), *Pinus* pollen fluctuates around 60%. This zone also includes notable quantities of *Picea*, *Pseudotsuga* and *Pinus monticola* pollen, whereas non-arboreal elements are not nearly as abundant as they were in the preceding three zones.

b) Vegetation and climate reconstruction

High *Pinus* pollen values of PHL-1 strongly suggest that *Pinus contorta* forest or parkland occupied the area immediately after deglaciation. Climate was probably cool and dry, but the vegetation may have had a pioneering character to it too.

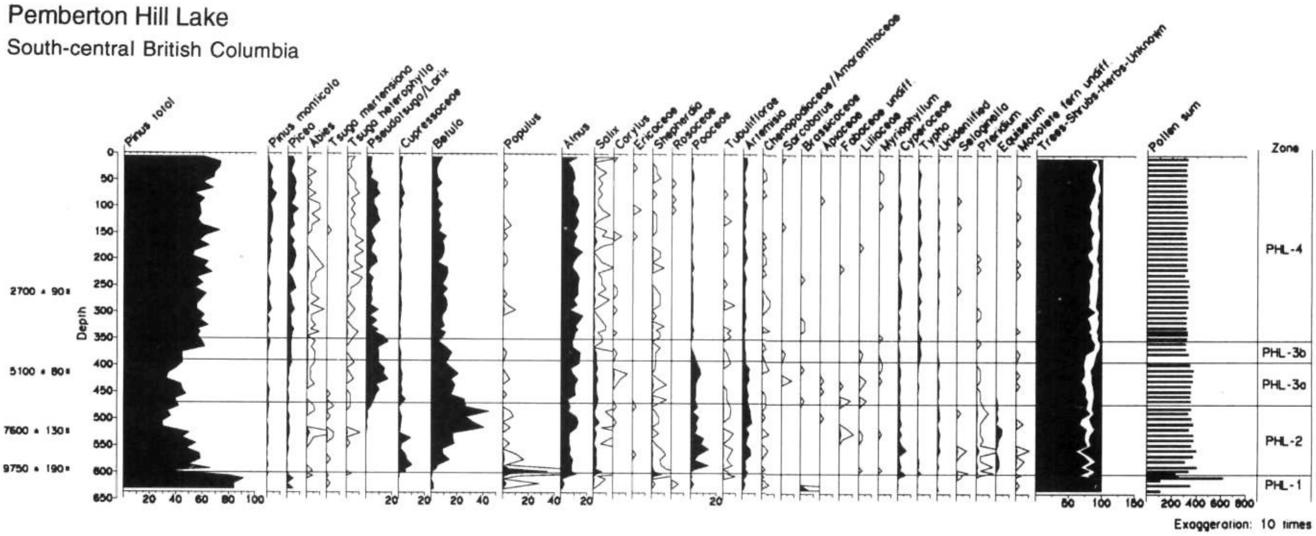


FIGURE 6. Relative pollen diagram for "Pemberton Hill" Lake, Richard Hebda analyst. Diagram prepared by Terrain Sciences, Geological Survey of Canada, Ottawa.

Diagramme de pourcentages polliniques de « Pemberton Hill » Lake (analyses de Richard Hebda). Diagramme réalisé par la Division de la science des terrains, de la Commission géologique du Canada, à Ottawa.

Pine stands were replaced briefly by an unusual combination of *Populus*, Cupressaceae and *Shepherdia* probably representing a *Populus-Juniperus* woodland with a well developed *Shepherdia* understorey. *Populus* stands, possibly of *Populus tremuloides,* grew around Finney Lake in the late-glacial time but not in combination with Cupressaceae (Hebda, 1982a). The location and overall climatic setting imply that a species of *Juniperus*, most likely *Juniperus scopulorum* Sarg. (Rocky Mountain Juniper) was the source of Cupressaceae pollen at Pemberton Hill Lake (Hazell, 1979; Hebda 1982b).

Because *Juniperus* continued as a predominant element during the first half of the zone, accompanied by grasses and *Artemisia*, the landscape was very open. Probably grass- or sage-dominated communities occupied lower elevations and the valley floor around the basin, whereas juniper woodland occurred in moister settings. Increasing *Betula* pollen values suggest that *Betula papyrifera* may have predominated on high and cool slopes. In the second half of the zone wooded portions of the landscape supported extensive stands of *Betula*, although openings remained on the valley bottom. Except for the time of the basal *Populus* pollen peak, climate must have been much warmer and drier than today. High *Betula* pollen values in the latter half of the zone suggest that moisture began increasing before 7000 BP.

From 7000-4000 BP *Pseudotsuga* forests, probably with significant *Betula*, covered much of the landscape (see Tsukada, 1982 and Hebda and Allen, 1993 for under-representation of *Pseudotsuga* pollen). However sites immediately around the lake still supported open vegetation. The climate must have been moister than the preceding zone where only traces of *Pseudotsuga* pollen occur, but warmer than post-4000 BP time.

Today's IDF forests in the valley took shape only in the last 4000 years as open grass and *Artemisia* communities essentially disappeared, and *Picea* (possibly *Picea engelmannii*) combined with *Pseudotsuga*, *Betula* and *Pinus* to form closed forests. Scattered haploxylon pines, probably *Pinus monticola*, occupied moist montane sites. Climate was moderate and moist as it is today.

The Pemberton Hill Lake record indicates that the 6000 BP climate was moister than early Holocene climate with much of the adjustments occurring at or before 7000 BP. However forest composition and persistence of openings indicate that temperatures at 6000 BP must have been warmer than today, possibly by 1C°. Thus at this site, 6000 BP fell into a 3000-year interval of climate warmer and at least effectively drier than today.

Pollen records from the southern Interior Plateau indicate that the 6000 BP horizon followed a warm to hot and dry early Holocene climate. Moisture began to increase between 8000 and 7000 BP and lakes began to fill. Between 7000 and 6000 BP forests expanded and composition changed yet open communities remained in what now is forested terrain. The climate was moist, but probably still warmer than today except possibly near Kelowna (Alley, 1976) and at Richter Marsh (Cawker, 1983). A comprehensive study of a lake cores from the BG zone is needed to resolve this difference in climatic interpretation. Only about 4000 BP did open communities disappear from mid elevation valleys and were replaced by modern forests under modern climate.

NORTHERN INTERIOR PLATEAU

The rolling landscape of this cool dry climate supports predominantly boreal forest vegetation, SBPS in the south and SBS in the north (Research Branch, 1988). A significant extension of IDF, characteristic of a warmer climate, occurs at the southern limits of the region (Fig. 2). A large area of MS occupies the southwest corner and provides the transition to ESSF followed by AT at high elevations.

This region is of particular climatic significance, because under conditions warmer and drier than today, dominant southern elements such as *Pseudotsuga*, and xeric open vegetation of grasses and lowland *Artemisia* could have extended north of their current limits. On the other hand, cooler or moister climates might have seen expansion down slope of predominantly montane and subalpine taxa such as *Abies lasiocarpa*.

To date only two radiocarbon-dated studies, to be published in detail elsewhere, one from Heckmann Pass in the Plateau-Coast Mountain transition (Hebda and Allen, unpublished) and one in the centre of the region near Quesnel (Hebda, unpublished), provide insight into the vegetation and climatic history of this region.

The record from Dwarf Birch Lake, Heckmann Pass (1450 m) (Fig. 1, #31), shows apparently little major change in vegetation and climate throughout the Holocene. *Pinus contorta* dominates pollen spectra throughout. However, examination of *Picea* and *Abies* curves and those of relatively uncommon taxa suggests that just before 6000 BP climate became moister and possibly cooler. At this time, and extending until about 3800 BP, *Abies* and *Picea* pollen increased with respect to *Pinus*, with *Abies* becoming as abundant as one might expect in the upper reaches of ESSF surface spectra (Hebda and Allen, 1993). At the same time *Betula* increased as well, suggesting bog development at the lake margin or expansion of one of the tree birches in response to moisture at the expense of *Pinus*. In general, the climate was clearly moister than in the early Holocene. Assemblages after 3800 BP, with less *Abies* pollen, again suggest the return of drier conditions.

At Pantage Lake (Fig. 1, #32), in the SBS, *Pinus* predominates in the pollen record from the beginning of the sequence about 9200 BP. However there are fluctuations in two important indicators, Poaceae and *Picea*. The early Holocene until *ca.* 7000 BP has relatively high Poaceae pollen values, in part consistent with what might be expected in vegetation characterized by significant openings. About 7000 BP Poaceae values decline to nil. *Picea* pollen values rise *ca.* 5000 BP. In general the climate must have become more moist between 8000 and 7000 BP (Poaceae decline), remaining moist to the present. The expansion of *Picea* with respect to *Pinus ca.* 5000 BP may signal cooling, coincident with a shift of conditions from those of the SBPS zone to the SBS zone. Early Holocene spectra at Pantage Lake resemble surface spectra from SBPS, where pine clearly predominates over spruce. Those of the late Holocene with more spruce pollen resemble surface spectra from SBS where spruce is more abundant (Hebda and Allen, 1993).

Despite the limited records in the region, the 6000 BP horizon follows or coincides with a time of increasing moisture. The temperature in the heart of the region (Pantage Lake) may have been slightly warmer than today, whereas in the Coast Mountains to Plateau transition it may have been cooler. Further studies are needed to clarify this apparent difference.

COLUMBIA MOUNTAINS AND SOUTHERN ROCKIES

The mountainous landscape of southeast B.C. exhibits great topographic, climatic and ecologic variation. Low elevations of the southern Rocky Mountain Trench (RMT) support tongues of PP and IDF zones. Most other mid- to low valleys are covered by ICH. Mid- to subalpine elevations are covered mainly by ESSF stands with restricted MS patches in the extreme southeast. Extensive stretches of AT and glaciers occupy the summits.

Six investigations provide insight into Holocene vegetation and climate history. Two of these (Hazell, 1979; Hebda, described in detail herein) come from the low to mid-elevations of the RMT, three (Kearney and Luckman, 1983; Fergusson and Hills, 1985; Reasoner and Hickman, 1989) represent sites in the Rocky Mountains, and one (Hebda, unpublished) represents moist mid-elevation forests of the western edge of the region.

Dunbar Valley

Hazell (1979, summarized in Ritchie, 1987) prepared the first comprehensive postglacial climatic and vegetation record for the region from Dunbar valley (Fig. 1, #33). In two lake cores from IDF to MS vegetation he recognized initial late Pleistocene (pre-10 000 BP) forest tundra dominated by *Pinus contorta* with *Artemisia* and herbs in openings. From 10 000-8000 BP much of the landscape was dominated by shrubs such as *Juniperus*, *Shepherdia* and *Salix*, then later *Betula* and *Alnus*. *Pinus* spp. were "probably common on less exposed sites, or on sites with better developed soils" (Hazell, 1979: 67). *Artemisia* values remained relatively high, consistent with significant open patches (Hebda, 1982b). The forest canopy closed after 8000 BP because *Pseudotsuga/Larix*, *P. contorta*, *Picea* and *Betula* pollen increased, whereas *Juniperus* declined sharply. This *P. contorta*-dominated forest persisted until the present with slight increases (Ritchie, 1987: 114) in *Abies* and *Picea* pollen at 4700 BP. At this time ESSF elevation limits declined and open xeric communities retreated southward according to Hazell (1979).

Hazell (1979) does not emphasize the sudden *Juniperus* decline followed by a sharp rise in *Betula* at Dunbar and Twin Lakes about 7000 BP. He focuses rather on the expansion of conifers such as *Pinus*. I suggest that this change in the pollen diagram and interpreted vegetation strongly signals increasing moisture. Xeric stands of *Juniperus* (assumed to be *J. scopulorum*) were either invaded by *Betula papyrifera* or *Betula occidentalis* moved into a newly developed moist shoreline zone around both lakes.

Using modern vegetation analogs and temperature lapse rates, Hazell (1979) calculated the mean July temperature at 7000 BP to have been 1.8C° higher than today. The 6000 BP horizon is included in a pollen assemblage similar to that at 7000 BP suggesting that it too fell into warm middle Holocene interval. There is a prominent *Alnus* pollen rise just before 6000 BP following the *Betula* increase at both lakes suggesting that climate was even moister than when *Juniperus* declined. Thus the 6000 BP level seems to have followed an interval of increasing moisture, during temperatures as warm or perhaps slightly warmer than today.

Bluebird Lake

"Bluebird" Lake (an informal name applied by R. Hebda) sits at 950 m on a mid-elevation terrace above the main floor of the Rocky Mountain Trench, just south of Canal Flats (Fig. 1, #34; Fig. 7). IDF zone forest surrounds the lake, but PP communities occur in the valley bottom only 10 km to the south. MS and ESSF stands occupy mountain slopes 2 and 4 km respectively to the west. Trunk glacier ice had receded from the RMT by 10 000 BP (Clague, 1975; Fulton, 1971) and possibly earlier from tributary valleys such as the Elk River valley (Clague, 1981; Fergusson and Hills, 1985).

Bluebird Lake is about 500 m long by 250 m wide, with a maximum depth of 5.0 m. *Scirpus* stands occupy shallow water at the south end. *Pseudotsuga* and *Larix occidentalis* Nutt. (western larch) predominate in the surrounding forest. Scattered *Pinus ponderosa* and *Picea engelmannii* also occur.

The base of the core is coarse grit (6.30-6.40 m), which is overlain by grey clay with shells from 5.60-6.30 m. Black slimy gyttja extends from 4.55-5.60 m. The remainder of the core consists of brown marly gyttja, becoming progressively less marly toward the surface. Alternating dark and light bands occur from 4.00-4.40 m. Fine grey tephra, assumed to be Mazama ash, occurs from 3.95-4.00 m. Radiocarbon dates are summarized in Table I.

a) Pollen zones

The earliest zone (BBL-1: 6.20-4.30 m: *Pinus*-Cupressaceae-NAP) spans 11 500 (extrapolated)-8500 BP (Fig. 8). It is characterized by medium to high pine values (50-80%), relatively abundant Cupressaceae (5-20%), some *Betula* (mostly 5-10%) and relatively abundant *Artemisia* pollen (5-15%). In the lower part of the zone (subzone BBL-1a, 11 500-10 400 BP) *Picea* pollen values range mostly between 5-10%. BBL-1a also exhibits the highest NAP values for the sequence with *Artemisia* abundant, and includes *Shepherdia*, Poaceae, *Ambrosia* type and Cyperaceae. In subzone BBL-1b relative total NAP and its constituents all decline although pollen accumulation rates increase — a possible artifact of sediment change at the zone BBL1a-1b boundary.

Zone BBL-2 (BBL-2: 4.30-1.30 m: *Pinus-Betula*) from 8500-1700 BP spans the middle Holocene and includes the 6000 BP horizon. *Pinus* (45-70%) and *Betula* (5-25%) constitute the principal pollen types. *Betula* pollen reaches the highest values throughout the core at about 2.50 m, then declines markedly at 2.30 m (*ca.* 4000 BP). *Alnus* and *Picea* values rise slightly from the preceding zone. *Pseudotsuga*/*Larix* pollen is established as a permanent element. NAP is generally low, but the highest values of Poaceae (3-5%) occur between 3.80 and 4.30 m.

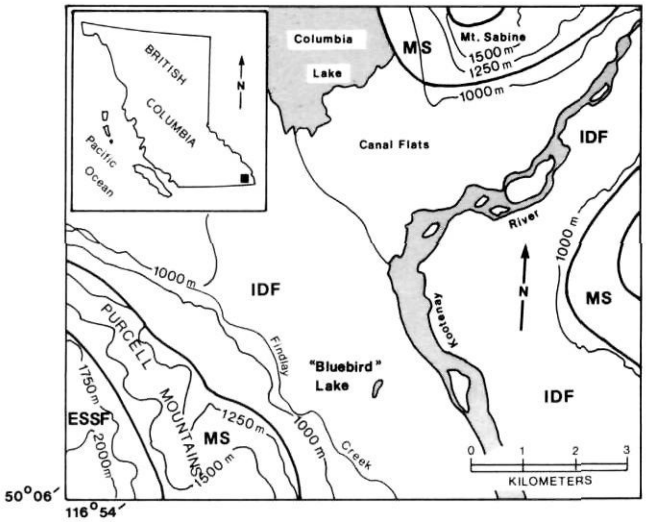


FIGURE 7. Location and vegetation zones of the "Bluebird" Lake study site and surrounding area.

Localisation et zones de végétation du site de «Bluebird Lake» et des environs.

Pseudotsuga/*Larix* type increases to more than 12% to begin zone BBL-3 (BBL-3: 0.00-1.30 m: *Pinus-Pseudotsuga*/*Larix*) which extends from 1000 BP to the present. *Pinus* remains predominant but less abundant than at the end of BBL-2. *Betula* continues as an important component and increases to over 20% just before the present.

b) Vegetation and climate reconstruction

Zone BBL-1 vegetation probably represents *Pinus contorta* - *Juniperus* parkland on the slopes with *Artemisia*-dominated assemblages on dry sites and in the valley bottom. High pine values clearly indicate that a diploxylon type (assumed to be *Pinus contorta* in the late glacial and very early Holocene) was a predominant woodland element. However Hebda and Allen (1993) demonstrated that values below 80%, when coupled with strong signals from other types, may not imply continuous *Pinus* cover. High NAP values, especially *Artemisia*, mark the occurrence of unforested tracts (Hebda, 1982b). As at Pemberton Hill Lake relatively high Cupressaceae values are assigned to *Juniperus*, not moisture-requiring *Thuja*. *Juniperus scopulorum* predominates in parkland communities in the bottom of the RMT today. *Juniperus communis* L. (common juniper) and *Juniperus horizontalis* Moench (creeping juniper) occur too, but would have contributed much less pollen than the tree species.

The first half of the zone before 10 400 BP was apparently more open than the second half. *Picea* must have played a much greater role, possibly occupying relatively moist settings. BBL-1 vegetation probably resembled closely the "forest tundra" vegetation envisaged in the Dunbar Valley by Hazell (1979).

Assuming the prevalence of openings, the climate of BBL-1 was drier than today. Relatively high *Picea* values for BBL-1a suggest a cooler climate than BBL-1b. High *Juniperus* and *Artemisia* values suggest that BBL-1b climate was probably warmer and drier than today.

The increase of *Betula* pollen at the start of BBL-2 signals the expansion of tree birches *Betula papyrifera* Marsh.

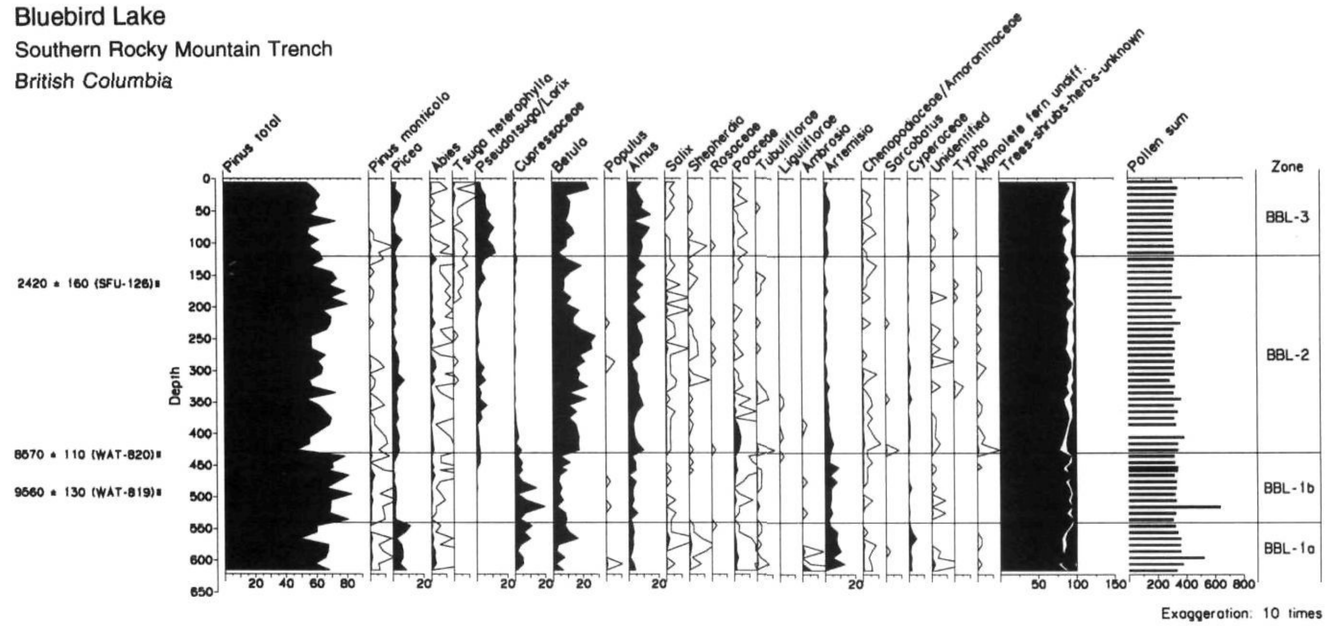


FIGURE 8. Relative pollen diagram from "Bluebird" Lake, Richard Hebda analyst. Diagram prepared by Terrain Sciences, Geological Survey of Canada, Ottawa.

Diagramme de pourcentages polliniques de « Bluebird » Lake (analyse de Richard Hebda). Diagramme réalisé par la Division de la sciences des terrains, de la Commission géologique du Canada, à Ottawa.

and/or *Betula occidentalis* Hook. Either or both of the following changes imply increased moisture. *B. papyrifera* expanded in the forest presumably at the expense of *Pinus*. *B. occidentalis* became more abundant in moist sites, possibly forming a lake-margin zone as the species does around many lakes today. *Pseudotsuga* and/or *Larix* arrive in the area and become significant elements of the increased forest cover. The two types cannot be reliably separated. These changes about 8500 BP point to increased moisture in the region and parallel increased forest cover at Dunbar Valley (Hazell, 1979).

In the early stages of the zone (8500-7500 BP) relatively abundant grasses suggest persistence of open but less xeric vegetation than in the preceding *Artemisia*-dominated communities. This thousand-year interval may have been slightly moister than BBL-1b, but less moist or with less effective moisture than the remainder of BBL-2.

Relatively moist climate continued throughout the rest of the Holocene; fluctuations in *Betula* and *Pinus* curves suggest some climatic adjustments. For example the *Betula* pollen decline at 2.30 m may indicate cooling at about 4000 BP. By the start of zone BBL-3 around 1700 BP, *Pseudotsuga* and/or *Larix* had become major forest types. Perhaps at this time temperature increased slightly favouring one or both of these over *Betula* and *Pinus*. Hazell's (1979) record shows a similar change.

At Bluebird Lake the 6000 BP horizon clearly falls into a climatic regime moister than the early Holocene, though the relative temperature is difficult to infer. Climatic adjustments occurred before the horizon, being mostly complete before 7500 BP though some vegetation changes might be the result of differential species migration. Relative stability followed to the present with possible cooling at 4000 BP and warming at 1700 BP. Forests of 6000 years ago were similar to those today.

Lower Little Slocan Lake

I analyzed a *ca.* 8000 year pollen record from a lake about 725 m elevation in the bottom of a broad valley within the ICH zone located about 40 km west of Nelson, British Columbia (Fig. 1, #35). The detailed results will be published elsewhere.

From 8000-6800 BP *Pinus* dominates pollen spectra, but relatively high values of *Abies*, *Picea*, and *Pseudotsuga/Larix* suggest a mixed conifer forest. *Artemisia* values reach over 5% indicating that the forests may have been open and nearby south-facing bluffs, which today support small patches of meadow, were covered in extensive non-forest vegetation. Between 6800 and *ca.* 5000 BP *Pinus* pollen increases slightly, *Picea* predominates over *Abies*, *Artemisia* declines and *Pseudotsuga/Larix* pollen continues as a notable element. The mixed conifer forests persist but dry openings are reduced. Climate is slightly moister than before. At 5000-4000 BP, arrival of *Tsuga heterophylla* pollen and slightly later Cupressaceae (assumed to be *Thuja plicata*) in combination with preceding types, signal the development of modern ICH forest. These grow under a moist climate, slightly cooler than in the preceding interval.

The 6000 BP horizon falls into a time when mixed conifer forest surrounded the lake as it does today. However *T. heterophylla* and *T. plicata*, indicators of cool moist climate, were absent, although they may not have migrated into the region at this time. Openings disappeared so climate was moister than in the early Holocene, although slightly warmer and possibly drier than after 5000 BP.

Tonquin Pass

A study in Tonquin Pass (Fig. 1, #36) at the B.C.-Alberta border provides insight into the history of high elevations (Kearney and Luckman, 1983). The record from stream-cut sections in bogs at 1935 m spans about 10 000 years. The site occurs within the upper ESSF where valley bottom bogs prevail because of cold air drainage.

The first thousand years (TC-1) are dominated by *Pinus* with notable *Abies* under cool and moist climate. Deposition of woody peat between 9000-8000 BP suggests drying of the bog surface. The climate according to Kearney and Luckman was cool because of increased haploxylon pine pollen values assumed to be from *Pinus albicaulis*. However increased warmth might have counteracted the cold air drainage effect and allowed more trees to grow closer to the site producing the increases in tree species percentages including *P. albicaulis*, relative to regional *P. contorta*.

The 6000 BP horizon falls into Kearney and Luckman's (1983) Zone TC-3 during which they envisage the emergence of the modern ESSF forest. In the early part of the zone they suggested that *Picea* and *Abies* expanded onto local meadows and fens which had dried out in response to a drying climate. Warm Hypsithermal conditions culminated about the time of Mazama Ash fall *ca.* 6800 BP, when canopy cover was almost complete across the pass floor. After 6800 BP Kearney and Luckman (1983) see a gradual decrease in trees and presumably cooling. However they define Hypsithermal conditions to extend from *ca.* 8000-4300 BP and to include the 6000 BP horizon. They interpret the climate from 4300 BP to the present as cooler and moister than in the Hypsithermal. Thus according to Kearney and Luckman (1983) it appears that in the high Rockies of southeastern British Columbia, the 6000 BP horizon represents nearly the warmest climate of the Holocene.

Elk Valley

Fergusson and Hills (1985) described 13 400 years of vegetation history from a peat bog in the ESSF at 1586 m elevation, upper Elk River valley near the B.C.-Alberta border (Fig. 1, #37). They resolved the pine pollen-dominated record into zones with emphasis on pine/spruce+fir ratios and Douglas-fir pollen percentages (assuming size separation of Douglas-fir from larch). Following pioneering shrub (*Betula-Artemisia*)-herb communities, *Picea* and *Abies* stands developed briefly in the early Holocene before being joined by *Pinus*. From 9600 (Hebda's calculation) - 8300 BP pine and spruce forest, possibly with *Abies* occurred, although high *Picea* pollen percentages suggest spruce and *Abies* forest predominated briefly 8700-8300 BP. Assuming Fergusson and Hills (1985) correctly distinguish Douglas-fir from larch pollen, Douglas-fir grew in the area from 8700-6500 BP with abundant pine. Fergusson and Hills (1985) attribute this vegetation in part to frequent fires and to climate warmer and drier than today. They also suggest an upward shift of the lower tree line. After 6500 BP the establishment of modern "cooler and moister" climate, and presumably development of modern ESSF forests, is interpreted from a decrease in pine/spruce+fir pollen ratios and Douglas-fir pollen. Fergusson and Hills (1985) do not note the increase in *Abies* pollen about 4500 BP (1.0 m in the profile). *Abies lasiocarpa* is recognized as being underrepresented in pollen rain (Hebda and Allen, 1993), so I suggest that this increase represents a major expansion of *Abies*. Such expansion would most likely have occurred as a result of cooling and possibly increased moisture. If my adjustment to Fergusson and Hill's (1985) interpretation is accepted then 6000 BP climate was transitional between warm dry conditions of the early Holocene and cool moist conditions of the later Holocene.

O'Hara and Opabin Lakes

Reasoner and Hickman (1989) provide more insight into the vegetation and climate history of the ESSF (Lake O'Hara, 2015 m above mean sea level) and adjacent AT (Opabin Lake, 2280 m above mean sea level) zones of the southern Rocky Mountains (Fig. 1, #38). A colonizing shrub-herb assemblage of *Artemisia*, Poaceae and *Alnus* surrounded Lake O'Hara before 10 100 BP and Opabin Lake before 8500 BP. The first forests at both sites contained *Pinus albicaulis* Engelm. (white-bark pine) and/or *Pinus flexilis* James (limber pine) and *Abies* with some *Picea* and *Pinus* cf. *contorta*. The upper tree line was located above Opabin Lake from 8500-3000 BP, 90 m higher than today, during which time modern ESSF forests were established. Reasoner and Hickman (1989) provide convincing pollen and macrofossil evidence that high tree line position was established by 8500 BP. They conclude, in contrast to Kearney and Luckman (1983) that this time exhibited climate warmer than present.

Picea and *Abies* forests with shrubby *Betula glandulosa* and herbs predominated from 7000 to 4000 BP. Reasoner and Hickman (1989) ascribe the open character of the forest to warmer and drier than present climates, and argue that diatom analyses support this conclusion. Relative decline of pine pollen, especially *Pinus contorta* could also be the result of increased moisture. Dry sites previously occupied by *P. contorta* may have become inhabited by shrubs and herbs. Increased moisture might have also reduced fire frequency further diminishing the regional and local abundance of *P. contorta*. Notably both diatom bloom peaks in the Opabin Lake sequence (Reasoner and Hickman, 1989: Fig. 10) occur after volcanic ash deposition, and may be related to silica input rather than climatic factors. Because the 6000 BP mark falls into this interval it becomes critical to establish whether the data support warm and moist or warm and dry climate states.

At Lake O'Hara culmination of a gradual rise in the *Picea* pollen curve and relatively high *Abies* pollen values suggest that modern ESSF forests and modern climate developed about 4000 BP according to my recalculation of Reasoner and Hickman's (1989: Fig. 5) lower boundary date for LOH 25 zone 4. Cooling climate lead to the development of AT vegetation at Opabin Lake by 3000 BP.

The 6000 BP climate of the Columbia Mountains and southern Rockies is not as easy to interpret as for the southern Interior Plateau. The 6000 BP horizon fell into an interval of increasing moisture which began as early as 8500 throughout the region with the possible exception of Lake O'Hara and Opabin Lake. As far as temperature goes, Tonquin Pass, Dunbar Valley, Elk River valley, Lake O'Hara and Opabin Lake records suggest it was more than 1C° warmer than today, whereas at the lower elevation sites of Bluebird and Lower Little Slocan Lake it appears at best to have been slightly warmer. Cooling and/or increased moisture seems to occur at all of the sites later. The timing is not clearly synchronous although 4000 BP seems to be a recognizable time of change. More sites representing latitudinal and elevational variability from this diverse landscape need to be investigated to resolve or confirm these differences.

NORTHERN BRITISH COLUMBIA

This enormous region encompasses many biogeoclimatic zones (Fig. 2) and physiographic units. For its diversity and size only a few records, mainly from the western (Banner *et al.*, 1983; Gottesfeld *et al.*, 1991; Miller and Anderson, 1974; Cwynar, 1988; 1994; Spooner, 1994) and eastern margins of the region (White and Mathewes, 1982; MacDonald, 1984, 1987) provide insight into vegetation and climate history.

Western margin

Banner *et al.* (1983) described a 8700 year sequence from a bog woodland near Mt. Hayes in the CWH zone near Prince Rupert (Fig. 1, #39). The authors interpret the earliest assemblage of *Pinus*, *Alnus* and monolete Polypodiaceae (Zone HM-1) to reflect a colonizing community on an alluvial surface. A *Picea sitchensis - Alnus - Tsuga heterophylla - Lysichitum* - Polypodiaceae assemblage (HM-2) follows about 8000 BP (Hebda's estimate), and reflects a moist alluvial forest. Between about 7000-6000 BP (authors' estimate) a less productive Cupressaceae-*Tsuga-Pinus* (HM-3) scrub forest replaces the more productive forest of the previous interval as peat accumulates on the forest floor. About 3200 BP (Hebda's estimate) bog woodland (HM-4) of *Pinus*, *Chamaecyparis*, Ericaceae and *Sphagnum* develops.

The sequence is ascribed both to climatic changes and edaphic factors linked to climate. Banner *et al.* (1983) suggest the change from zone HM-2 to HM-3 may reflect a cooling and moistening trend between 7000 and 6000 BP. The earlier two zones, when forests were more productive and little peat accumulated, may reflect relatively warm and dry climates of the early Holocene. They suggest that increased moisture and decreased temperatures just before 6000 BP may have triggered "succession from productive forest to scrub" (Banner *et al.*, 1983:945). The shift to bog woodland may be the result of non-climatic edaphic factors or may represent further cooling and increased moisture.

Because there is only a single radiocarbon date at the base, identification of the 6000 BP horizon has to assume a constant sediment accumulation rate. The horizon falls at *ca.* 1.35 m, a level in zone HM-3 with exceptionally high *Pinus*, and just within the zone where herbaceous peat replaces woody peat.

Further inland at Seeley Lake in the Skeena River Valley (Fig. 1, #40) within the ICH zone, Gottesfeld *et al.* (1991) described vegetation and climatic history from a lake core spanning almost 10 000 years. The first zone (SL-1) ends just before the 6000 BP mark. It is interpreted to represent a mixed forest of *Picea* and *Abies* with extensive successional stands of *Populus trichocarpa*, *Betula papyrifera*, and *Pinus contorta*. *Alnus* occupied riparian sites. Gottesfeld *et al.* (1991) noted that fires were probably common and possibly reflected warmer and drier climate than today. From 6150-4700 BP (zone SL-2) a trend to wetter climate is interpreted from increased *Tsuga heterophylla* pollen and decreased seral taxa, especially *Pinus*. Cooling and moist conditions continue from 4700-2200 BP as *T. heterophylla* increases further. The last two millennia reflect the arrival of *Thuja plicata* in the region but include an "enigmatic" increase in *Pinus* pollen, possibly linked to aboriginal burning of lowland sites (Gottesfeld *et al.*, 1991).

The 6000 BP horizon is notable in this area, as it is at Mt. Hayes, because it falls just at the beginning of an interval of increased moisture. At both localities the pollen curve of *Tsuga heterophylla*, a tree of moist climates, increases just before the horizon. On the coast increasing moisture is also indicated by paludification, whereas in the drier more continental interior it appears that it is marked by declining fire frequency.

Recently Spooner (1994) described a 9000 year pollen and macrofossil record from Susie Lake, in AT, at 1460 m near a point of convergence of ESSF and SWB zones of northwest B.C. (Fig. 1, #41). Colonizing shrub (*Alnus*, *Salix*, *Shepherdia*) and herb (Poaceae, *Artemisia*) vegetation (9000-7800 BP) was replaced by *Picea* and *Abies* forest under the influence of warmer-than-present climate 7800-4200 BP. On the basis of increased Cyperaceae pollen, Spooner (1994: 230) suggests generally moister climate in this interval compared to the preceding one. Spooner (1994) interprets the interval from 4200-2100 BP to reflect cooling and increasing moisture. *Picea* needles disappear, whereas *Abies* needles remain abundant. *Betula* pollen increases suggesting the development of openings in my opinion. Increased *Pinus* pollen (to 30%) may imply migration of pine to the region but certainly not to the site (Hebda and Allen, 1993). I suggest that the pollen and macrofossil assemblage probably represents *Abies lasiocarpa*-dominated parkland clearly indicating the beginning of cool climate at 4200 BP. The upper tree line declined below the elevation of the lake and modern cold and moist climate became established 2100 BP with the local disappearance of *Abies* (based on absence of needles).

Several sites on both sides of the B.C.- Yukon border, near Atlin, British Columbia (Fig. 1, #43,44), provide insight into the climate of the extreme northwest of the province (Miller and Anderson, 1974; Cwynar, 1988). Most of the sites fall into the BWBS or its Yukon equivalent. The early Holocene begins with shrub tundra, which quickly converts to spruce woodland about 9000 BP (Miller and Anderson, 1974). From 8000 to 5500 BP, *Picea glauca* forest predominates, whereupon it is replaced by *Picea* forest with *Alnus* until *ca.* 3200 BP. Three short-lived zones follow, involving *Picea*, first with *Abies* and then with *Pinus*. Simplified climatic trends include early Holocene warming with increasing moisture to generally warm and wet conditions from 8000-3200 BP, followed by cooling. The 6000 BP mark falls at about the time of maximum warmth and wetness. The main warming, about 4.5C°, took place between 9000-7000 BP (Miller and Anderson, 1974: Fig.9).

Nearby, at Kettlehole Pond (Fig. 1, #44) in the southern Yukon, Cwynar (1988) confirms that the 6000 BP horizon fell into a time of wetter climate than today. Effective moisture increased between 9250-6100 BP, with the climate becoming very moist between 6100-4100 BP. Today's semiarid climate began to return at 4100 BP. In Cwynar's 5500 year record from Waterdevil Lake, near the Alaskan border (Fig. 1, #42) (SWB zone) middle Holocene *Alnus*, *Picea* and *Betula* pollen assemblages are replaced by *Pinus contorta-Abies* assemblages *ca.* 3100 BP. Cwynar (1994:118) suggests a change (= decline?) "in the frequency of penetration of coastal air masses" presumably leading to more xeric climate.

Eastern margin

Far to the east, three records from the BWBS zone represent the Holocene history of the Alberta Plateau and adjacent Rocky Mountain slopes of B.C. (White and Mathewes, 1982; MacDonald, 1984, 1987). White and Mathewes (1982) reported the development of a seasonal slough in the basin of Fiddler's Pond (Fig. 1, #45) about 7200 BP in response to increased moisture (increased precipitation or decreased evapotranspiration). Climate was too hot and dry in the early part of the Holocene to support a permanent water body. Slough conditions persisted until 5500 BP. During the slough phase boreal forest (*Pinus* and *Picea*) grew on surrounding upland sites; boreal forest persists to the present. At 5500 BP a permanent pond, surrounded by sedge wetlands, became established as moisture increased. Modern climatic conditions were established at 3100 BP, possibly as a result of slight cooling.

At 6000 BP the climate had become effectively moister than in the early Holocene. However the main increase in effective moisture did not occur until 5500 BP. Relative temperature is hard to interpret, except that White and Mathewes (1982) imply that it must have been slightly warmer than today if cooling is responsible for changes at 3100 BP.

MacDonald (1984, 1987) suggests that early Holocene vegetation in the region was shaped by soil development and delayed migration of species especially pine. At Snowshoe Lake (Fig. 1, #46), before 10 000 BP, sparse vegetation of *Populus*, shrubs and herbs occurred (MacDonald, 1987). From 10 000 to about 8500 BP (Hebda's estimate) *Picea glauca* forest dominated. Between 8000 and 7300 BP (Hebda's estimate) *P. glauca*, *Picea mariana* and *Betula papyrifera* stands occurred, joined near the end of the interval by *Pinus*. Between 7300 and 6000 BP *Betula* pollen values declined reflecting a decline in tree birch in the forest, whereas *Pinus* pollen and trees became more abundant. Fires increased from 8000-6000 BP in nearby Alberta sites (MacDonald, 1987). Modern "subalpine-boreal transition forest", fire regimes and presumably climate were established about 6000 BP with a major increase in *Alnus crispa*. MacDonald (1987) concludes, from increases in abundance of pollen and spores of muskeg taxa, that peatlands and muskegs characteristic of the region developed between 8000 and 4000 BP as a result of cooling and moistening. These reached their modern extent by 5000 BP (MacDonald, 1987:317).

Open *Artemisia* and Poaceae herbaceous communities occurred at Lac Ciel Blanc (Fig. 1, #47) before 10 000 BP, followed briefly by shrub birch and *Populus* vegetation until 9500 BP (MacDonald, 1984). Spruce forest with *Populus* and *Betula papyrifera* developed at this time and persisted until about 7000 BP (MacDonald, 1984: Figs. 22, 50). Though spruce forest still persisted, increased *Alnus* and *Myrica* pollen and decreased birch suggest that the landscape was wetter than before. A second increase in *Alnus* pollen *ca.* 6000 BP and a increase in *Pinus* pollen *ca.* 5500 BP, associated with a decrease in *Picea* pollen, suggest that spruce forest persisted and gradually became modified into BWBS between by 5000 BP. Based on detailed analysis of *Picea* pollen at Wild Spear Lake, nearby in Alberta, *Picea mariana* predominated in the forest after 5500 BP, whereas before that time both *P. mariana* and *P. glauca* were major forest species (MacDonald, 1984).

The 6000 BP horizon at Lac Ciel Blanc and Snowshoe Lake, like that at Fiddler's Pond (White and Mathewes, 1982), occurred during a time of increasing moisture and possibly cooling. Yet pollen assemblages were not quite like those today, raising the question whether the climate was similar to today's especially with respect to temperature or not.

Generally, 6000 BP in northern B.C. occurs during an episode of increased moisture compared to the early Holocene. However as might be expected from such a large sparsely studied region the beginning of the wet trend varies. In the west it begins between 6000 and 7000 BP. In the east and north it has already begun by 7000 BP. Warmer temperatures than present are suggested or implied pre-7000 BP continuing to 4700 or 3100 BP especially at western margin sites. Cooling seems to occur latest in the extreme north. The major time of cooling on the eastern margin is not clear, perhaps as early as the middle Holocene if we accept MacDonald's (1984, 1987) interpretations or later, if the changes at Fiddler's Pond at 3100 BP (White and Mathewes, 1982) are the result of cooling. At this time there are too few records to be certain of the northern B.C. temperature state and/or trend at 6000 BP.

Tree lines

Clague and Mathewes (1989) showed for southern British Columbia that the upper tree line stood higher than present throughout most of the first half of the Holocene until about 5000 BP. In some regions tree line declined to its present position as late as 2000-3000 years ago (Reasoner and Hickman, 1989; Spooner, 1994). Tree line data support the concept of a warmer than present early Holocene, but also suggest that even the 6000 BP mark fell into a climate warmer than today. According to Clague and Mathewes (1989), climate was warmest between 9100 and 7600 BP, followed by a gap from 7600 to 6600 BP for which there are no logs above tree line at the sites they examined. From 6600-5100 BP there are records of logs above present tree line in British Columbia. Luckman and Kearney (1986) also record higher-than-present tree lines for the early and middle Holocene in adjacent Alberta. They concluded that alpine timberlines have been similar to present or lower since 4500 BP. Luckman and Kearney (1986) estimate that at 6000 BP in the central Rocky Mountains mean annual temperatures were about 1.2C° warmer than present. How much warmer than present high elevations of the different regions of B.C. were at the 6000 BP mark remains to be seen because Ryder and Thomson (1986) observed evidence for onset of Neoglaciation in the Coast Mountains between 6000 and 5000 BP.

DISCUSSION

VEGETATION AND THE 6000 BP HORIZON

Coastal vegetation histories from the Queen Charlotte Islands to Vancouver Island, despite a gap on the adjacent mainland, present a consistent sequence. A widespread *Pinus contorta* paleobiome develops after the retreat of glacial ice under cool and probably relatively dry conditions. Only on the Queen Charlotte Islands was there tundra-like vegetation upon the disappearance of ice (Mathewes, 1989). Along the coast short-lived forest assemblages, involving variously *Picea*, *Abies*, *Tsuga* spp., and *Pinus* in mixed conifer forests, characterize the transition from the pine paleobiome to vegetation of the early Holocene, probably under a cool and moist climate. A Younger Dryas-like return to cold climate may occur briefly during this transition. Marked changes between 10 000 and 9000 BP include the arrival and spread of *Pseudotsuga menziesii* in the south, and establishment of *Picea sitchensis* - *Tsuga heterophylla* forests in outer coastal and northern sectors. Non-arboreal vegetation develops in the rain shadow of southeast Vancouver Island.

Changes continue through the middle Holocene with expansion of *Tsuga heterophylla* about 7500-7000 BP. Another notable adjustment occurs in the 5000-4000 millennium, when Cupressaceae (largely *Thuja plicata*) expand throughout the region and the adjacent U.S. northwest (Hebda and Mathewes, 1984). Bogs develop and/or expand at this time too. Modern vegetation becomes established between 4000 and 2000 BP, though adjustments continue into the most recent millennium.

In the southern Interior, the early Holocene was characterized by open xeric communities with abundant grasses and *Artemisia* at many localities, even those forested today. Changes began as early as 8500 BP and intensified to 7000 BP at which time forests, including *Pseudotsuga*, expanded downslope and *Artemisia* declined. Water levels rose and new lakes formed. About 4500-4000 BP open vegetation disappeared from middle elevation valleys and modern forests developed. Tree lines were highest then descended during the middle Holocene.

Lodgepole pine has dominated parts of central Interior landscapes throughout the Holocene, but open communities were extensive at low elevations until *ca.* 7000 BP. At high elevations *Abies* and *Picea* played a greater role between 6000 and 3800 BP, whereas at lower elevations *Picea* increased about 5000 BP.

Northern B.C. sites are few and scattered, and the interpretation of the vegetation history complicated by the time-transgressive migration of *Pinus*. Sites from extreme northern and northeastern B.C. began with early Holocene non-arboreal vegetation which changed to *Picea*-dominated (mainly *Picea glauca*) forests. *Pinus* joined these communities in these regions in the middle Holocene. *Abies* in the northwest and *Picea mariana* in the northeast expanded after the middle Holocene especially post- 4000 BP. Tree lines in the north appear to have been higher at 6000 BP than today.

From this vegetation summary it is clear that 6000 BP vegetation differed from extant communities throughout the province, even though most major taxa were in place near their current ranges. These differences thus were in large part the result of climatic regimes unlike those today.

CLIMATE TRENDS

States *vs* Trends

Knowing the state or conditions of climate at a specific point in time in comparison to an established reference state, such as modern climate, is essential for climatic modelling. It is also essential for the purposes of unambiguous comparison from region to region. Figure 9 depicts generalized regional Holocene climatic states and trends for the regions of British Columbia. States and trends are derived from interpretations of the original authors. However some authors did not always distinguish the climatic state (temperature and precipitation compared to modern state) for a given interval separately from the trend. Rather they expressed climatic conditions with reference to previous climates (warmer and drier, cooler and wetter) or as trends (increasing moisture, drying).

It is especially important to define the climatic state around the 6000 BP mark because past studies have interpreted or implied conflicting conditions, especially with respect to temperatures (see Heusser *et al.*, 1985, coast; *vs* Mehringer, 1985, interior). In many analyses, with the exception of those involving transfer functions, tree lines or lake levels, the reader is left puzzled as to what "cooling and moistening" actually means with respect to present-day conditions. The middle Holocene exhibits both cooling and moistening trends, yet a cooling trend which extends from 7000-4000 BP may still leave 6000 BP climate warmer than today and hence in a different state. I attempted to clear up potential confusion between trends and states by interpreting states from a comparison of regional records and being clear in the interpretation of my own records. The schemes

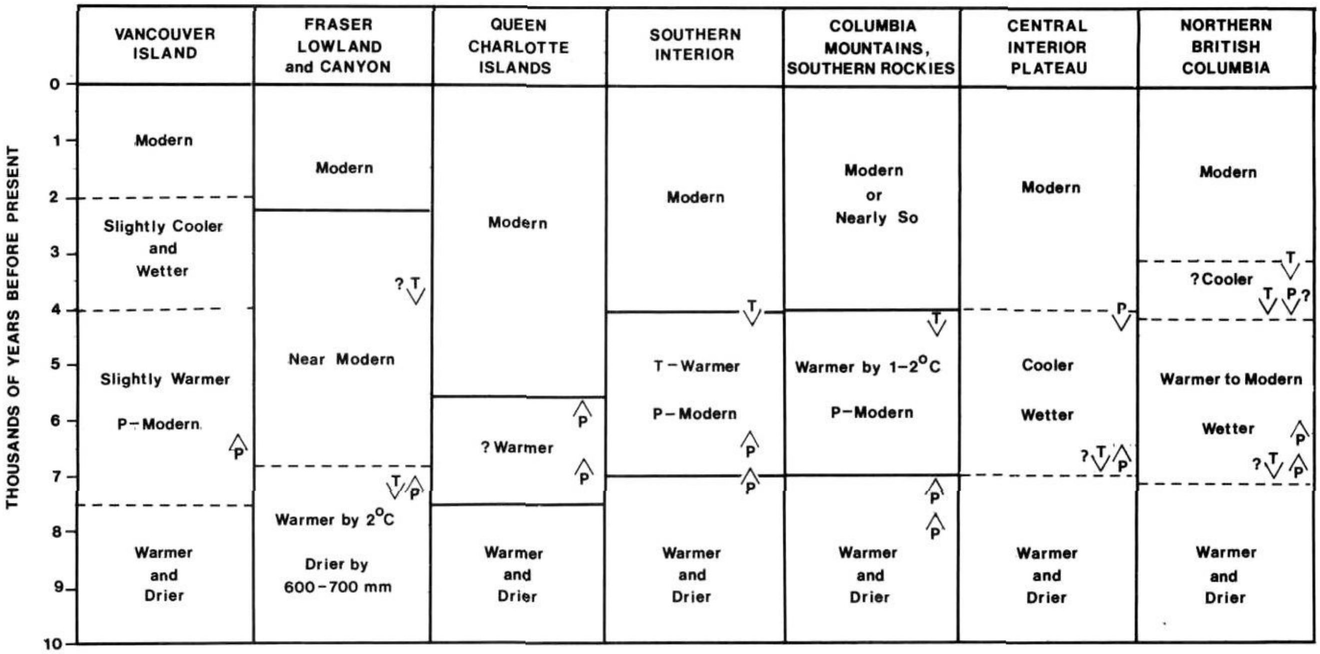


FIGURE 9. Summary of Holocene climatic states and trends from British Columbia. P= precipitation, T= temperature. Solid boundaries denote times of marked change, dashed boundaries denote gradual or uncertain times of change.

Climats et tendances climatiques à l'Holocène, en Colombie-Britannique. P = précipitations; T = températures. Les limites en trait plein identifient des périodes de grands changements; les limites en tirets identifient des périodes incertaines ou de changements graduels.

for central and north British Columbia are least confident because of the few sites studied and great ecological diversity.

The Holocene encompasses three major climatic states or intervals: 1) a warm dry "xerothermic" climate *ca.* 9500-*ca.* 7000 BP, 2) a warm moist "mesothermic" climate *ca.* 7000-*ca.* 4500 BP, and 3) moderate moist climate 4500-0 BP. Following rapid warming at the beginning of the Holocene there are two major climatic trends 1) increasing moisture from 8000-6000 BP, concentrated between 8000 and 7000 BP, and possibly associated with minor cooling, 2) cooling, possibly with minor increased precipitation, mainly between 4500-3000 BP.

The start and end times for the states and trends vary somewhat from region to region, and depend on the sensitivity and thresholds of the proxy record (*e.g.*, glaciers *vs* pollen) and the sophistication and precision of interpretations. Climate change in northern B.C. sites appears to lag behind events to the south, for example increasing moisture seems to be concentrated between 7000 and 6000 BP (see also southern Alaska (Heusser *et al.*, 1985)). In the extreme north and Alberta Plateau the most marked cooling occurs closer to 3000 BP rather than 4000 BP.

Precipitation

Consistent with previous regional summaries, I interpret the early Holocene as much drier than present (Hebda, 1982b; Heusser, 1985; Heusser *et al.*, 1985; Mathewes and Heusser, 1981; Mathewes, 1985). Precipitation began to increase about 8000 BP with sufficient increase so that by 7000 BP major changes were initiated in the vegetation of southern B.C. Modern levels of effective precipitation seem to be reached by 6000 BP especially in the south (Mathewes and Heusser, 1981; Heusser *et al.*, 1985). In the extreme north the middle Holocene may have been slightly drier than today with precipitation continuing to rise for another millennium (Heusser *et al.*, 1985).

The middle Holocene, including the 6000 BP horizon, was wetter than the early Holocene and perhaps as wet as today, as evidenced by expansion of moisture-liking species such as western hemlock, descending lower tree lines, relatively full lakes, and reduced fire frequencies (Mathewes, 1985). On the coast bogs began to form and expand in the middle Holocene too, although the major expansion took place after 5500 BP.

Vegetation and bog changes following 5500 BP have been ascribed in part to increasing moisture and to cooling. In these circumstances, the changes in these two climatic factors are difficult to distinguish on the basis of pollen studies alone. However other indicators such as tree line position and expanding glaciers suggest that a decline in temperature was the primary factor for late Holocene vegetation changes.

Temperature

Early Holocene mean annual temperatures were warmer by 2-4C° than those today and those preceding the Holocene (see also Barnosky *et al.*, 1987). It is difficult to establish precisely when temperatures passed today's means because of plant migrational and successional factors, but this probably occurred between 10 000 and 9000 BP. Temperatures rose to a maximum probably between 9000 and 7500

BP, though the trend to increasing moisture may have masked continued peak temperatures to at least 7000 BP. Kearney and Luckman (1983) considered warmest temperatures to have occurred closer to 6000 BP in the high Rocky Mountains. Mehringer's (1985) synthesis of U.S. Pacific Northwest inland sites indicates that warm temperatures continued until about 5400 BP. Feng and Epstein's (1994) study of hydrogen isotopes of Bristlecone pine wood from the southwestern United States places the thermal maximum near 7000 BP.

In British Columbia the temperature at 6000 BP with respect to modern temperatures is not at first glance clear. Mathewes (1985) recognized this by suggesting that the "so-called Hypsithermal" was "time transgressive". The summarized records in this paper strongly suggest that most of the province was warmer in the middle Holocene as indicated by the nature of plant communities, the extent of grasslands, and position of tree line thus placing 6000 BP in the Hypsithermal.

The start of cooling may have varied from area to area however. I interpret B.C. records to suggest temperatures warmer than or near today's values in most regions until about 5000 BP. Signs of major cooling such as glacier advances (Ryder, 1989) begin about 5500 BP, especially near the coast, and seem to be concentrated about 4500-3800 BP. The clearest indications of cooling occur about 4000 BP with changes in vegetation on the coast and in the interior (Fig. 9) and further Neoglacial ice advances (Ryder, 1987). Temperatures reach modern values or may even briefly decline below modern values at this time. More or less present-day temperatures become established from 4000 BP to the present though regional adjustments continue especially in northern B.C.

The synthesis of records for B.C., besides pointing out clearly the need for more studies, provides a revealing perspective on Holocene climates, especially those near 6000 BP. I argue that there is strong evidence that the warmer than present interval had two parts to it, an early Holocene (9500 -7000 BP) warm dry or "xerothermic interval", as suggested by Mathewes and Heusser (1981) and a warm wet "mesothermic interval" (proposed herein) from 7000-4500 BP. The mesothermic by my definition begins when annual precipitation rises to present day levels while temperatures remain warmer than present. The precise end of the mesothermic depends on the time that mean annual temperatures reach those of the present day. This end point is difficult to specify, because of the inherent imprecision in core chronologies and the difficulty of distinguishing the direct effects on vegetation of precipitation from temperature-related moisture availability (*i.e.*, effective precipitation). Even tree line declines may have built-in delays. In general, the transition from a warm state to cool state seems to occur between 5000 and 4000 years ago throughout most of the province.

The recognition of a mesothermic is particularly important for the correlation of B.C. Holocene climates with those elsewhere in North America, especially eastern Canada. There the warm interval is typically referred to as the Hypsithermal (as defined by Deevey and Flint, 1957). In the west the Hypsithermal has generally been seen as occurring earlier and somewhat out phase with the east (Mathewes, 1985), although in earlier works (*e.g.*, Heusser, 1960) it did span the middle Holocene and the 6000 BP mark. If the concept of the mesothermic interval is accepted then the end of the western Hypsithermal corresponds well with the end of the eastern Hypsithermal. Ritchie (1987:137) noted how "climates similar to modern began ... about 4000 yr BP", remarkable coherence across the continent. Closer to B.C. in the U.S. interior northwest, Mehringer (1985) notes 4000 BP as a significant time of climate change. However the 7000 BP horizon, so prominent a point of change in British Columbia, appears not to be a major horizon in the east (Ritchie, 1987). In part this may be a result of the extreme precipitation gradients in B.C. compared to eastern North America. These are particularly important because 7000 BP changes are largely precipitation related. In part it may be because eastern climates were under the influence of wasting Laurentide Ice well into the Holocene. Notably the prominent increase of jack pine pollen in some records from the modern boreal forest of the western Interior (Ritchie, 1987:101-103) occurs about 7000 BP and suggests, in part, a connection between climatic histories of the two regions.

This synthesis draws together for the first time the extensive but patchy paleoecological records for all of British Columbia. Much work remains to be done especially in the north, to refine climatic chronologies and interpretations from pollen records and resolve the temperature and precipitation components of climate. The 6000 BP mark seems to fall into a warm and moist interval whose end approximates the end of warm climates in eastern Canada. Further studies should focus not only on areas from which there are no cores but on techniques independent of pollen analysis, such as oxygen isotopes, lake levels, and upper tree line positions, to clarify the nature of precipitation and temperature for 6000 BP. The exceptional sequence of tree discs from Heal Lake on Vancouver Island (Hebda, 1993), which almost certainly includes the 6000 BP horizon, will shed light on this time. Perhaps most important of all, the sensitivity and variety of sites in British Columbia holds great promise for providing detailed proxy data for climatic modelling.

ACKNOWLEDGEMENTS

I am most thankful to Rolf Mathewes, Simon Fraser University, Burnaby, for taking the time to discuss aspects of the climate and vegetation record of British Columbia and for a thorough and constructive review. Alwynne Beaudoin's (Archaeological Survey, Alberta) review was very helpful, as were her discussions about eastern B.C. records. Les Cwynar, University of New Brunswick, Fredericton, provided valuable insight into the climate history of the B.C.-Yukon area. Jerry Osborne, Geology and Geophysics, University of Calgary, helped me get important recent material. Allen Banner, Research Branch, Ministry of Forests, Victoria checked over sections of the manuscript and helped secure permission to use the biogeoclimatic zone map (Fig. 2). Derryl Fedje, Parks Canada at Calgary, generously provided access to his M.A. thesis. Kendrick Brown and Qi-bin Zhang, School for Earth and Ocean Sciences checked over parts of the manuscript.

I thank Tom Bown and James Haggarty of Victoria for help with coring Bluebird Lake and Pemberton Hill Lake respectively. Tom Bown and Bob Powell of Victoria prepared samples for pollen analysis for these two sites. Dave Gillan drafted diagrams.

To Hélène Jetté I express my gratitude for many hours of constructive discussion on the phone, help with decisions concerning format and content, plotting pollen diagrams, and obtaining support to print Figure 2 in colour. Diagrams were prepared at the Geological Survey of Canada, Ottawa, using the "Tiliagraph" computer program.

The studies of Pemberton Hill and Bluebird Lakes were supported by funds from the Royal British Columbia Museum and Archaeology Branch, Province of B.C., Victoria.

REFERENCES

Allen, G.B., 1995. Vegetation and climate history from the CDF and CDF/CWH transition on south east Vancouver Island. M.Sc. thesis. School of Earth and Ocean Sciences, University of Victoria.

Allen, G.B. and Hebda, R.J., 1993. Forest history of south Vancouver Island British Columbia, since deglaciation. Abstract in Program with Abstracts and Field Guide. Canadian Quaternary Association Meeting, April 18-21, 1993, Victoria, B.C., p. A1.

Alley, N.F., 1976. The palynology and palaeoclimatic significance of a dated core of Holocene peat, Okanagan Valley, southern British Columbia. Canadian Journal of Earth Sciences, 13: 1131-1144.

Anderson, R.Y., Nuhfer, E.B. and Dean, W.E., 1984. Sinking volcanic ash in uncompacted sediment in Williams Lake, Washington. Science, 225: 505-508.

Bacon, C.R., 1983. Eruptive history of Mount Mazama and Crater Lake Caldera, Cascade Range, U.S.A. Journal of Volcanology and Geothermal Research, 18: 57-115.

Banner, A., Pojar, J. and Rouse, G.E., 1983. Postglacial paleoecology and successional relationships of bog woodland near Prince Rupert, British Columbia. Canadian Journal of Forest Research, 13: 938-947.

Barnosky, C.W., Anderson, P.M. and Bartlein, P.J., 1987. The northwestern U.S. during deglaciation: Vegetational history and paleoclimatic implications. *In* W.F. Ruddiman and H.E. Wright, Jr., eds., North America and adjacent oceans during the last deglaciation. Boulder, Colorado, Geological Society of America, The Geology of North America, v. K-3.

Brown, T.A, Nelson, D.E., Mathewes, R.W., Vogel, J.S. and Southon, J.R., 1989. Radiocarbon dating of pollen by Accelerator Mass Spectrometry. Quaternary Research, 32: 205-212.

Cawker, K.B., 1983. Fire history and grassland vegetation change: Three pollen diagrams from southern British Columbia. Canadian Journal of Botany, 61: 1126-1139.

Clague, J.J., 1975. Late Quaternary geomorphology of the southern Rocky Mountain Trench, British Columbia. Canadian Journal of Earth Sciences, 12: 595-605.

—— 1981. Late Quaternary geology and geochronology of British Columbia: Part 2: Summary and discussion of radiocarbon-dated Quaternary history. Geological Survey of Canada Paper, 80-35: 1-41.

Clague, J.J. and R.W. Mathewes, 1989. Early Holocene thermal maximum in western North America: New evidence from Castle Peak, British Columbia. Geology, 17: 277-280.

Cwynar, L.C., 1988. Late Quaternary vegetation history of Kettlehole Pond, southwestern Yukon. Canadian Journal of Forest Research, 18: 1270-1279.

Deevey, E.S. and Flint, R.F., 1957. Postglacial hypsithermal interval. Science, 125: 182-184.

Ecoregions Working Group, 1989. Ecoclimatic Regions of Canada, First Approximation. Ecoregions Working Group of the Canada Committee on Ecological Land Classification. Ecological Land Classification Series, No. 23, Sustainable Development Branch, Canadian Wildlife Service, Conservation and Protection, Environment Canada, Ottawa, 119 p.

Fedje, D.W., 1993. Sea-levels and prehistory in Gwaii Haanas. M.A. thesis, Department of Archaeology, University of Calgary.

Feng, X. and Epstein, S., 1994. Climatic implications of an 8000-year Hydrogen isotope time series from Bristlecone Pine trees. Science, 265: 1079-1081.

Fergusson, A. and Hills, L.V., 1985. A palynological record, Upper Elk Valley, British Columbia, p. 370-396. *In* C.R. Harington, ed., Climatic Change in Canada 5: Critical Periods in the Quaternary Climatic History of Northern North America. Syllogeus 55.

Fulton, R., 1971. Radiocarbon geochronology of southern British Columbia. Geological Survey of Canada, Paper 71-37: 1-28.

Gottesfeld, A.S., Mathewes, R.W. and Gottesfeld, L.M.J., 1991. Holocene debris flows and environmental history, Hazelton area, British Columbia. Canadian Journal of Earth Sciences, 28: 1583-1593.

Hansen, H.P., 1947. Postglacial forest succession, climate and chronology, in the Pacific Northwest. Transactions of the American Philosophical Society (N.S.) 37(1).

Hare, F.K. and Thomas, M.K., 1979. Climate Canada, 2nd Edition. John Wiley and Sons, Toronto.

Hazell, S., 1979. Late Quaternary vegetation and climate of Dunbar Valley, British Columbia. M.Sc. thesis. Department of Botany, University of Toronto, 101 p.

Hebda, R.J., 1977. The paleoecology of a raised bog and associated deltaic sediments of the Fraser River Delta. Ph.D. thesis. University of British Columbia, Vancouver, 201 p.

—— 1982a. A 13,000 year record of vegetation, Hat Creek Valley, southcentral British Columbia. Abstracts, American Quaternary Association Seventh Biennial Conference, Seattle, Washington, p. 99.

—— 1982b. Postglacial history of grasslands of southern British Columbia and adjacent regions, p. 157-191. *In* A.C. Nicholson, A. McLean, and T.E. Baker, eds., Grassland Ecology and Classification Symposium Proceedings. British Columbia Ministry of Forests, Victoria.

—— 1983. Late-glacial and postglacial vegetation history at Bear Cove Bog, northeast Vancouver Island, British Columbia. Canadian Journal of Botany, 61:3172-3192.

—— 1984. Postglacial vegetation history of Brooks Peninsula, Vancouver Island, British Columbia. Abstracts. 6th International Palynological Conference, August 26 - September 1, 1984, Calgary, Canada. p. 62.

—— 1993. Climate history, Heal Lake, Vancouver Island, British Columbia. Program with Abstracts and Field Guide. Canadian Quaternary Association Meeting, April 18-21, 1993, Victoria, B.C. p A20.

—— (in press). Late Quaternary Paleoecology of Brooks Peninsula. *In* R.J. Hebda and J.C. Haggarty, eds., Brooks Peninsula: A Glacial Refugium. Royal British Columbia Museum.

Hebda, R.J. and Allen, G.B., 1993. Modern pollen spectra from west central British Columbia. Canadian Journal of Botany, 71: 1486-1495.

Hebda, R.J. and Mathewes, R.W., 1984. Holocene history of cedar and Native Indian cultures of the North American Pacific Coast. Science, 225: 711-713.

Heusser, C.J., 1960. Late-Pleistocene environments of North Pacific North America. American Geographical Society Special Publication No. 35.

—— 1985. Quaternary pollen records from the Interior Pacific Northwest Coast: Aleutians to the Oregon-California boundary, p. 141-165. *In*

V.M. Bryant and R.G. Holloway, eds., Pollen Records of Late-Quaternary North American Sediments. American Association of Stratigraphic Palynologists Foundation, Dallas.

Heusser, C.J., Heusser, L.E. and Peteet, D.M., 1985. Late-Quaternary climatic change on the American North Pacific Coast. Nature, 315: 485-487.

Heusser, L.E., 1983. Palynology and paleoecology of postglacial sediments in an anoxic basin, Saanich Inlet British Columbia. Canadian Journal of Earth Sciences, 20: 873-885.

Kearney, M.S. and Luckman, B.H., 1983. Postglacial vegetation history of Tonquin Pass, British Columbia. Canadian Journal of Earth Sciences, 20: 776-786.

Krajina, V.J., Klinka, K. and Worrall, J., 1982. Distribution and characteristics of trees and shrubs of British Columbia. Faculty of Forestry, University of British Columbia, Vancouver, 131 p.

Luckman, B.H. and Kearney, M.S., 1986. Reconstruction of Holocene changes in alpine vegetation and climate in the Maligne Range, Jasper National Park, Alberta. Quaternary Research, 26: 244-261.

MacDonald, G.M., 1984. Postglacial plant migration and vegetation development in the western Canadian boreal forest. Ph.D. thesis, University of Toronto.

—— 1987. Postglacial development of the subalpine-boreal transition forest of western Canada. Journal of Ecology, 75: 303-320.

Mathewes, R.W., 1973. A palynological study of postglacial vegetation changes in the University Research Forest, southwestern British Columbia. Canadian Journal of Botany, 51: 2085-2103.

—— 1985. Paleobotanical evidence for climatic change in southern British Columbia during Late-glacial and Holocene time, p. 397-422. *In* C.R. Harington, ed., Climate Change in Canada 5: Critical Periods in the Quaternary Climatic History of Northwestern North America. Syllogeus 55.

—— 1989. Paleobotany of the Queen Charlotte Islands, p, 75-90. *In* G.G.E. Scudder and N. Gessler, eds., The Outer Shores. Based on the Proceedings of the Queen Charlotte Islands First International Symposium, University of British Columbia, August 1984. 327 p.

—— 1993. Evidence for Younger Dryas-Age cooling on the North Pacific Coast of America. Quaternary Science Reviews, 12: 321-331.

Mathewes, R.W. and Heusser, L.E., 1981. A 12,000-year palynological record of temperature and precipitation trends in southwestern British Columbia. Canadian Journal of Botany, 51: 707-710.

Mathewes, R.W. and King, M., 1989. Holocene vegetation, climate, and lake-level changes in the Interior Douglas-fir Biogeoclimatic Zone, British Columbia. Canadian Journal of Earth Sciences, 26: 1811-1825.

Mathewes, R.W. and Rouse, G.E., 1975. Palynology and paleoecology of early postglacial sediments from the lower Fraser River Canyon of British Columbia. Canadian Journal of Earth Sciences, 12: 745-756.

Meidinger, D. and Pojar, J. (eds,), 1991. Ecosystems of British Columbia. Research Branch, Ministry of Forests, British Columbia, Victoria.

Mehringer, P.J., Jr., 1985. Late-Quaternary pollen records from the interior Pacific Northwest and northern Great Basin of the United States, p. 167-189. *In* V.M. Bryant and R.G. Holloway, eds., Pollen Records of Late-Quaternary North American Sediments. American Association of Stratigraphic Palynologists Foundation, Dallas.

Miller, M.M. and Anderson, J.H., 1974. Out-of-phase Holocene climatic trends in the maritime and continental sectors of the Alaska-Canada Boundary Range, p. 33-58. *In* W.C. Mahaney, ed., Quaternary Environments: Proceedings of symposium. York University, Geographical Monographs No. 5.

Pojar, J. and Meidinger, D., 1991. British Columbia: The environmental setting, p. 39-67. *In* D. Meidinger and J. Pojar, eds., Ecosystems of British Columbia. Research Branch, Ministry of Forests, British Columbia. Victoria.

Pojar, J., Meidinger, D. and Klinka, K., 1991. Concepts, p. 9-37. *In* D. Meidinger and J. Pojar, eds., Ecosystems of British Columbia. Research Branch, Ministry of Forests, British Columbia, Victoria.

Quickfall, G.S., 1987. Paludification and the climate on the Queen Charlotte Islands during the past 8000 years. M.Sc. thesis, Department of Biological Sciences, Simon Fraser University, Burnaby, 99 p.

Reasoner, M.A. and Hickman, M., 1989. Late Quaternary environmental change in the Lake O'Hara Region, Yoho National Park, British Columbia. Palaeogeography, Palaeoclimatology, Palaeoecology, 72: 291-316.

Research Branch, 1988. Biogeoclimatic zones of British Columbia, 1988. Map 1:2,000,000. Ministry of Forests, British Columbia, Victoria.

Ritchie, J.C., 1987. Postglacial Vegetation of Canada. Cambridge University Press, 178 p.

Rowe, J.S., 1972. Forest Regions of Canada. Canadian Forestry Service, Department of the Environment, Ottawa, Publication No. 1300.

Ryder, J.M., 1987. Neoglacial history of the Stikine-Iskut area, northern Coast Mountains, British Columbia. Canadian Journal of Earth Sciences, 24: 1294-1301.

—— 1989. Holocene glacier fluctuations (Canadian Cordillera) Chapter 1. *In* R.J. Fulton ed., Quaternary Geology of Canada and Greenland. Geological Survey of Canada, Ottawa, Geology of Canada No. 1.

Ryder, J.M. and Thomson, B., 1986. Neoglaciation in the southern Coast Mountains of British Columbia prior to the late Neoglacial maximum. Canadian Journal of Earth Sciences, 23: 273-287.

Spooner, I.S., 1994. Quaternary environmental change in the Stikine Plateau Region, northwestern British Columbia, Canada. Ph.D. thesis, Department of Geology and Geophysics, University of Calgary.

Stein, W.I., 1990. *Quercus garryana* Dougl. ex Hook Oregon White Oak, p. 650-660. *In* R.M. Burns. and B.H. Honkala, eds., Silvics of North America Volume 2, Hardwoods. Agriculture Handbook 654, Forest Service, United States Department of Agriculture, Washington D.C.

Tsukada, M., 1982. *Pseudotsuga menziesii* (Mirb.) Franco: Its pollen dispersal and late Quaternary history in the Pacific Northwest. Japanese Journal of Ecology, 32: 159-181.

Wainman, N. and Mathewes, R.W., 1987. Forest history of the last 12,000 years based on plant macrofossil analysis of sediment from Marion Lake, southwestern British Columbia. Canadian Journal of Botany, 65: 2179-2187.

Walker, I.R., 1988. Late-Quaternary palaeoecology of Chironomidae (Diptera: Insecta) from lake sediments of British Columbia. Ph.D. thesis. Department of Biological Sciences, Simon Fraser University, Burnaby. 204 p.

Walker, I.R. and Mathewes, R.W., 1989. Early postglacial chironomid succession in southwestern British Columbia, Canada, and its paleoenvironmental significance. Journal of Paleolimnology, 2: 1-14.

Warner, B.G., 1984. Late Quaternary paleoecology of eastern Graham Island, Queen Charlotte Islands, British Columbia, Canada. Ph.D. thesis. Department of Biological Sciences, Simon Fraser University, Burnaby, 190 p.

White, J.M. and Mathewes, R.W., 1982. Holocene vegetation and climatic change in the Peace River district, Canada. Canadian Journal of Earth Sciences, 19: 555-570.

Williams, H.F.L. and Hebda, R.J., 1991. Palynology of Holocene top-set aggradational sediments of the Fraser River Delta, British Columbia. Palaeogeography, Palaeoclimatology, Palaeoecology, 86: 297-311.

Zirul, D., 1967. Pollen analysis of a bog in the Garry Oak Zone of southern Vancouver Island, B.C. B.Sc. thesis, Department of Biology, University of Victoria, 38 p.