BioDiversity BC
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Biodiversity: Geological History in British Columbia

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Geologic history and landscape age play key roles in shaping the biodiversity of a region. In general, old stable landscapes support more species than young ones because evolution has longer to foster variation. Landscapes with complex geological histories tend to have more habitats because the land surface is diverse. Also geologically old regions likely experienced numerous geographic connections with sources of new biotic material from other regions.

Exceptional geological events such as glaciation and harsh climates reduce biodiversity and eliminate ecosystems. These events also create isolated pockets of life in which new evolutionary directions are explored (Hebda and Irving 2004). British Columbia has experienced widespread glaciation and harsh climates even in the past short 15,000 years (Clague 1989, Hebda and Whitlock 1997).

Global geological processes during the past 100 million years have variously connected and separated the BC region to the east, northwest and south bringing infusions from wide-ranging ecosystems and species and fostering in situ evolution. During much of the Cenozoic Era, the region was once part of a warm, temperate, broadleaf forest biome that extended across the northern hemisphere, then later part of the broad zone of conifer and deciduous forest that slowly replaced it (Graham 1999). The raw material for modern terrestrial biodiversity has its origins in these biomes (Hebda and Irving 2004). Temperatures declined in the last 10,000,000 years reaching the cool and cold climates of the Pleistocene (Ice Age) Epoch. During this cooling western North America evolved distinctive temperate and northern floras, faunas and biomes, as well as dry inter-mountain ecosystems (Graham 1999).

As terrestrial ecosystems developed in the Cenozoic, marine biodiversity was largely shaped by migrations north and south along the Pacific Coast as global temperatures fluctuated. Coastal marine ecosystems developed a north-south pattern of zones. Shoreline ecosystems were broadly similar to those today by 25 million years ago and the constituent species had close modern relatives. A major factor was the evolution of large marine mammals including whales.

The Pleistocene (Ice Age) Epoch

Major Pleistocene Epoch cooling beginning 1.8 million years ago initiated northern hemispheric migrations and progressive development of boreal and tundra biomes (Graham 1999). In British Columbia several widespread glaciations ranged across the province (Clague 1989), resetting the biodiversity page each time.

Taiga, tundra and cold dry steppe ecosystems spread widely across the continent including British Columbia, alternating in time with conifer forest ecosystems similar to those extant today. A distinctive Pleistocene-adapted, mammal megafauna ranged widely, and cold-adapted forms such as muskoxen extended into southern BC during cold intervals (Harington, 1975).

Before the Last Glacial Maximum: 50,000-17,000 years ago[1]*****

The most important interval concerning the origin and development of BC biodiversity extends back into the last 50,000 years, before the last ice major advances. The globe and North America were generally cooler with glacial ice probably occupying northeast North America and possibly some of our mountains. Vegetation zones were displaced southward and downward (400-500 m). In the adjacent Northwest US mixed conifer forest and cold open ecosystems, dominated by sage and pines in the interior, alternated in time and space (Whitlock and Bartlein 1997).

In BC, extensive subalpine spruce and mountain hemlock forests and parkland prevailed between about 48,000 and 30,000years ago (Armstrong et al. 1985, Fedje and Mathewes 2005). Wetlands seemed to have occurred widely and rivers and lakes may have been relatively loaded with sediment.

Cold and dry full-glacial conditions developed widely about 30,000 years ago and intensified to about 20,000 years ago. Steppe ecosystems seem to have prevailed including elements of the widespread megafauna such as woolly mammoths (Harington 2001). High elevation alpine species grew at sea-level (Mathewes 1979). Major glaciers occupied major valleys, in front of which occurred unstable stream and river systems transporting masses of sediment. A brief respite from full-glacial conditions occurred 17,000-18,000 years and sub-alpine like forest returned at least in southwest BC before the intense glaciation centred on 15,000 year ago (Lian et al. 2001).

The glacial maximum 17000-14000 years ago

The traditional view is that almost all of BC was glaciated during this last glaciation leading to a “de novo” origin of BC terrestrial biodiversity with migration of species from south, east and north. From this perspective BC’s biodiversity is a regional variation on evolutionary themes largely developed elsewhere. To a considerable extent this is the case, however, recent studies, especially of DNA (Marr et al. in review) suggest that the size of unglaciated zones, or refugia, is greater than previously thought and that elements of the province’s biodiversity have a long pre-glacial history in place.

The most widely recognized and accepted refugia are high elevation sites on Queen Charlotte Islands and Brooks Peninsula on Vancouver Is. (Hebda and Haggarty 1997, Fedje and Mathewes 2005). In these areas, alpine and probably high elevation cool

[1] All ages are in radiocarbon years not calendar years

oceanic ecosystems persisted, leading to a unique set of plant species and sub-specific lineages endemic to the region.

DNA studies of mountain sorrel (Oxyria digyna), a globally widespread alpine plant, also suggest ice-free zones for alpine species, in northern BC possibly with connections to Beringia. The studies also confirm the north coastal refugium. The extent to which low elevation sites were involved in the refugium is unknown, however the results point to the potential for a high level of genetic diversity and globally unique biodiversity in the region.

A key feature of the last glacial interval, despite the occurrence of refugia, is that no extensive conifer forests as we know them today existed in BC, though scattered coniferous trees such as subalpine fir at high elevations in the south (Heinrichs et al. 2002) and lodgepole pine along the coast (Hebda and Whitlock 1997) may have persisted. Our forest ecosystems as we know them all developed in the last 14,000 years as ice age climates ended.

In the near shore marine environment sea levels fluctuated widely and for several thousand years and the coastal marine zone was exposed to a depth of more than 100 metres. Many now isolated land masses such as the Queen Charlotte Islands were connected to the mainland facilitating migrations (Fedje and Mathewes 2005).

End of the Ice-age 14,000 to 10,000 years ago

Landscape instability continued for at least 4000 years as the glacial regime ended between 14000-10000 years ago. During this interval of widespread climatic and ecological adjustment, extensive migrations took place throughout the region and forest ecosystems began to re-form.

Three broad migration patterns overprinted British Columbia's unique alpine and coastal ecosystems that had survived glaciation. In the north, elements of the Beringian steppe-tundra landscape spread southward. From the south, two fronts of migration occurred, one along the coastal zone of largely coastal temperate rainforest species, and one east of the Coast-Cascades mountain axis of Great Basin cold steppe and dry forest species. Sweeping from the southeast along the waning Laurentide ice sheet also came continental boreal and conifer woodland species.

In some respects the ecosystems of this time of transition might have looked familiar though out of place. For example for several thousand years open dry cold lodgepole pine forests extended along B.C. coast to Alaska forming a distinctive biome (Hebda and Whitlock 1997). Inland, cold, sage and grass ecosystems likely predominated (Heinrichs et al. 2001). Tundra-like ecosystems spread across the north. Moist cool mixed coniferous forests developed for about a thousand years (12,000-11,000 years ago) from the pine biome along the coast, featuring mountain hemlock down to sea level elevations (Walker and Pellatt 2003). These ecosystems reflected the cooler-than-present climates of the day.

In one major respect however life on the late-glacial landscape differed from what we see today: the occurrence of the now extinct megafauna. Mastodons, giant bison, mammoth even giant ground sloth roamed parts of BC (Harington 2001). For example, numerous giant bison roamed widely across southern Vancouver Island and islands. These animals clearly influenced the ecological processes and structure and composition of plant communities. Along with the giant beasts, a new species, humans, began to depend upon and influence BC's evolving biological diversity.

In the fresh-water aquatic realm a degree of stability returned to the landscape as it became stabilized by vegetation. Familiar ecosystems such as cattail and bulrush marshes and shallow water aquatic communities developed widely. Lime rich marl depositing ecosystems occurred widely on the parts of the south coast and in the southern interior. The marine zone was however much less stable because of sediment input from waning valley glaciers and the invasion of ocean water on a glacially depressed landscape. Diverse cold water mollusc faunas predominated.

The glacial epoch ended not gradually but with a bang, recalibrating so-to-speak, the landscape. A brief but profound cooling event, called the Younger Dryas in Europe, brought cold dry conditions for about 500 years and widely disrupted the landscape (Mathewes et al. 1993) . Temperatures declined over a few decades by as much as 5 C, and cold climate processes such as solifluction disturbed the landscape as far south as Vancouver Island (Hebda unpublished data). There was widespread forest loss and return of cold and unstable ecosystems such as alder scrub along the coast (Mathewes et al. 1993). Migration and extinction of the ice-age megafauna took place globally and in British Columbia. As far as we know none of the big beasts survived the dramatic climatic and ecological changes into the Holocene epoch and non-glacial climates in BC. Human hunting exacerbated the disappearance of the megafauna.

Warm dry early Holocene Epoch 10,000-7,000 years ago

Around the world, rapid warming of as much as 5-8 C ushered in the warm interglacial climates of the modern Holocene Epoch. This period of roughly 10,000 years can be broadly divided into three climatic intervals during which B.C.'s pre-European disturbance biodiversity arose: warm relatively dry 10,000-7000, warm moist 7000-4000, moderate and moist 4000-present (Hebda 1995).

The warm dry early Holocene was a time of rapid in-migration and establishment of new ecosystems in many regions under climates warmer than today. On the south coast, Douglas-fir spread widely and rapidly to dominate forests and woodlands well into the zone of today's cedar hemlock forests (Brown and Hebda 2002a). Even in the moist climates of west Vancouver Island and the central and north coast, Sitka spruce combined with western hemlock to form an ecosystem without modern equivalent in BC (Hebda and Haggarty 1997).

Warm dry grasslands and Garry oak ecosystems, including many of the species we associate with them today, became established and occupied areas much greater than today. Beyond the grasslands in south interior BC, dry pine-dominated forests reached well into, if not fully occupying, today's extent of the Engelmann Spruce-Subalpine fir Biogeoclimatic zone (Heinrichs et al. 2001). Species now rare in BC such as Oregon ash, were much more widespread, whereas species common today such as western red-cedar occurred infrequently (Pellatt et al. 2001). Fires burned widely in the southern half of the province regularly disturbing the landscape in the interior and even on the coast (Brown and Hebda 2002b).

Extensive tracts of open ecosystems related to modern non-forest communities occurred widely during the warm dry early Holocene interval.

Many herbaceous and shrubby species (e.g. Artemisia) of open terrain had become well established in late glacial times especially during drier phases. To these were added species that migrated from the south following newly available warm to hot dry valley bottoms and slopes, each according to its natural rate of dispersal. In southern interior BC, valley-bottom grasslands stretched through a series of elevation zones upslope into alpine heights forming a large area suitable for rangeland dwellers (Hebda 1995, Heinrichs et al. 2001). Extensive steppe ecosystems reached as far north as the latitude of Quesnel. Along the south coast, sea levels were at least 10 m lower than now and many of our now uncommon, restricted or rare meadow coastal species spread throughout the Georgia Basin (Clague et al. 1982). Tree-lines stood higher than today and the alpine region was less extensive in the south.

What little we know about northern ecosystems during the warm dry interval, indicates the gradual development of boreal like forests involving spruces and migration of pine into the region. Yet even in northeast BC grasslands were more widespread (Hebda 1995). Freshwater aquatic environments were generally warmer and shallower than today, with some smaller water bodies being ephemeral (Mathewes and King 1989). Water chemistry tended toward neutral and even alkaline and marl depositing communities occurred widely in the southern interior. Marshes and swamps predominated in the wetland realm.

Conditions in the marine environment are not well known for this interval. Whereas the early Holocene was an interval of migration and connection on the south coast, isolation and fragmentation took place on the north coast as sea levels rose and separated the Queen Charlotte Islands from the continent, drowning extensive low-lying coastal ecosystems, eventually resulting in an island area much smaller than today (Fedje and Mathewes 2005).

Warm moist middle Holocene Epoch: 7000 - 4000 years ago

Increasing moisture and gradual cooling fostered major ecological changes between 7000-4000 years ago (Hebda 1995). In this transition to modern conditions, western

hemlock and Sitka coastal forests persisted, however Pacific silver-fir and western redcedar became more abundant. Dry south coastal regions continued to support Douglas-fir dominated ecosystems except on south-east Vancouver Island where extensive tracts of Gary oak woodland and meadow occurred (Pellatt et al. 2001).

Grasslands were widespread in the southern interior, but pine forests expanded down-slope. Engelmann spruce-subalpine fir forests began to appear in moist cool sites (Heinrichs et al. 2004) and boreal forest continued to develop in the north.

Topographic basins filled with greater amounts of permanent water (Hebda 1995). Ephemeral and small ponds expanded into lakes. Seasonally intermittent streams may have become permanent water courses. The wet shore zone accordingly expanded outwards and the volume of deep water grew. The marine shore line and its ecosystems now began to stabilize but major sea-level adjustments continued with inundation of low-lying areas in the inner south coast (Fraser Lowland) and emergence of shallow zones on the outer coast (Queen Charlotte Islands) (Clague et al. 1982).

Moderate and moist Late Holocene Epoch: 4000 -7000 years ago

The last 4000 years has seen cooler temperatures than in the preceding 6000 years and combined with relative abundance of moisture, fostered forest and wetland expansion. Only in this interval does the modern pattern of ecosystems become well established. Glaciers and ice fields expanded widely at high elevations.

On the coast the most important event is the widespread spread of western redcedar and the development of modern coastal temperate rain forests (Brown and Hebda 2002a). Dry ecosystems, such as the Garry oak meadow complex, became strongly limited in their range, though repeated use of fire by First Nations may have maintained them over a wider extent than the climate dictates (Brown and Hebda 2002b). The interior cedar hemlock forests arose for the first time (Hebda 1995, Rosenberg et al. 2003). At high elevations in the interior the cold moist forest of the spruce-subalpine fir zone became well established, largely developing from earlier relatively dry pine forests (Heinrichs et al.2004). Similarly coastal Mountain Hemlock forests developed fully and spread more widely (Pellatt and Mathewes 1997, Brown and Hebda 2003) In the central interior Sub-boreal spruce forests spread southward into areas previously too dry to support them. As forests spread on many fronts, grasslands shrank to their minimum extent where they largely remain today (Hebda 1995).

Associated with the cooling and moistening climate at 4000 years ago, the activity of fire declined notably. Nevertheless fires were used by first Nations throughout much of the province and at all elevations for maintaining resources associated with open and successional communities (Brown and Hebda 2002b).

Increasing moisture on the landscape fostered widespread growth of peatlands. Bogs arose or spread widely in wet coast forests and in moist interior climatic sectors providing

habitat for the distinct species associated with them. Other wetland and aquatic habitats expanded too. Mid-high elevation lakes and stream cooled as glaciers redeveloped and expanded (Palmer et al. 2002). Relative stability on land was paralleled by stability in the marine zone as sea-levels reached relative equilibrium following nearly 10,000 years of postglacial adjustment (Clague et al. 1982). Presumably the modern pattern of marine ecosystems became established at this time.

1850 to the present day

The last 4000 years of relative stability was sharply shaken by advent of European and Asian settlers. **Ecosystems that had taken thousands of years to develop have been profoundly disturbed especially in the southern part of the province by physical disturbance through land conversion and widespread logging, and invaded by exotic species, several of which found niches even in undisturbed habitats.**

The scale and rate of physical disturbance of the last century and a half has not been experienced for 10,000 years. Some coastal temperate rainforest regions have not been disturbed by any agent for at least 4000 years (Hebda and Brown 2002a). Biological and physical changes (erosion, nutrient release) in the landscape have led to major changes in the aquatic realm. Southern regions and ecosystems had seen a 25% increase in species richness through the addition of exotic species, often at the cost of native biodiversity. Not since the end of the Pleistocene had such a change in biodiversity occurred in the province. These invasions are still underway, and in northern parts of the province yet to take place in earnest.

Key summary points:

- BC landscape and seascape have a long and complex physical and biological history.
- Native biodiversity is derived from forest and non-forest species and ecosystems with long histories in the surrounding regions.
- BC's pattern of biodiversity in large part has relatively recent origins in response to wide-spread glaciation and subsequent rapid climate changes.
- Alpine ecosystems and populations may be old and unique as may also be related cold aquatic ecosystems.
- Hyper-oceanic coastal sites harbour unique species with long in-situ history.
- Grassland and related non-forest ecosystems were more widespread than today for much of the Holocene Epoch.

- The structure and composition and distribution of modern forest ecosystems are recent.

- Today's pattern and character of wetland ecosystems is less than 4000 years old.

- The disruption of BC's inherited biological diversity by historic and on-going land-use and invasion by non-native species is on a scale unseen for 10,000 years.

References

Armstrong, J.E., J.J. Clague and R.J. Hebda. 1985. Late Quaternary Geology of the Fraser Lowland, southwestern British Columbia. In D. Tempelman-Kluit, Editor. Field Guides to Geology and mineral deposits in the southern Canadian Cordillera. Geological Association of Canada, Vancouver. pp. 15-1 to 25.

Brown, K.J. and R.J. Hebda. 2002a. Origin, development, and dynamics of coastal temperate conifer rainforests of southern Vancouver Island, Canada. Canadian Journal of Forest Research 32:353-372.

Brown, K.J. and Hebda, R.J. 2002b. Ancient fires on southern Vancouver Island, British Columbia, Canada: A change in causal mechanisms at about 2,000 ybp. Environmental Archaeology 7: 1-12.

Brown, K.J. and Hebda R.J. 2003. Temperate rainforest connections disclosed through a late-Quaternary vegetation, climate, and fire history investigation from the Mountain Hemlock Zone on southern Vancouver Island, British Columbia, Canada. Review of Palaeobotany and Palynology, 123: 247-269.

Clague, J.J. 1989. Cordilleran Ice Sheet, pp. 40-42 *in* Cpater 1 of Quaternary Geology of Canada and Greenland. R.J. Fulton (ed.). Geological Society of North America, vol. K-1.

Clague, J.J., Harper, J.R., Hebda, R.J., and Howes, D.E. 1982. Late Quaternary sea levels and crustal movements, Coastal British Columbia. Canadian Journal of Earth Science 19:597-618.

Fedje, D.W. and R.W. Mathewes (eds). 2005. Haida Gwaii: Human History and Environment from the Time of the Loon to the Time of the Iron People. University of British Columbia Press 448 pp.

Graham, A. 1999. Late Cretaceous History of North American Vegetation North of Mexico. Oxford University Press.

Harington, C.R. 1975. Pleistocene muskoxen (Symbos) from Alberta and British Columbia. Canadian Journal of Earth Sciences 12: 903-919

Harington, C.R. (ed.) 2001. Annotated bibliography of Quaternary vertebrates of northern North America with radiocarbon dates. University of Toronto Press. 360 pp.

Hebda, R.J. 1995. British Columbia vegetation and climate history with focus on 6 KA BP. Geographie Physique et Quaternaire 49:55-79.

Hebda, R.J. and Haggarty J.C. (editors). 1997. Brooks Peninsula: An Ice Age Refugium on Vancouver Island. Occasional Paper No. 5. B.C. Parks. Victoria, B.C. 461 p.

Hebda, R.J. and E. Irving. 2004. On the Origin and Distribution of Magnolias: Tectonics, DNA, and Climate Change. In Timescales of the Paleomagnetic Field Geophysical Monograph Series (AGU) No. 145:43-57.

Hebda, R.J. and C. Whitlock. 1997. Environmental history of the coastal temperate rain forest of northwest North America. In Schoonmaker, P.K., von Hagen, B. and E.C. Wolf. Eds. The Rain Forests of home: Profile of a North American bioregion. Island Press, Covelo, CA. Pp 225-254

Heinrichs, M.L., J.A. Antos, R.J. Hebda, and G.B.Allen. 2002. Abies lasiocarpa (Hook.) Nutt. in the late-glacial and early-Holocene vegetation of British Columbia, Canada and adjacent regions in Washington, U.S.A. Review of Palaeobotany and Palynology 120:107-122.

Heinrichs, M.L., Evans, M.G. Hebda, R.J., Walker, I., and S. L. Palmer. 2004. Holocene climatic change and landscape response at Cathedral Provincial Park, British Columbia, Canada. Geographie Physique et Quaternaire 58:123-139

Heinrichs, M.L., Hebda, R.J. and Walker, I. 2001. Holocene vegetation and natural disturbance in the Engelmann Spruce - Subalpine Fir biogeoclimatic zone at Mt. Kobau, British Columbia. Canadian Journal of Forest Research 31:2183-2199.

Heinrichs, M.L., Hebda, R.J. and Walker, I., and S. L. Palmer. 2002. Postglacial paleoecology and inferred paleoclimate intervals in the Engelmann Spruce-Subalpine Fir forest of south-central British Columbia, Canada. Palaeogeography, Palaeoclimatology, Palaeoecology 148: 347-369.

Lian, O.B., Mathewes, R.W., and S.R. Hicock. 2001. Paleoenvironmental reconstruction of the Port Moody Interstade, a non-glacial interval in southwestern British Columbia about 18,000 14C years BP. Canadian Journal of Earth Sciences 38: 943-952.

Marr, K.L., Allen, G. A., and R.J. Hebda (in review). Gaps in the Cordilleran Ice Sheet of western North America: DNA evidence from the Arctic-alpine plant Oxyria digyna. Journal of Biogeography.

Mathewes, R.W. 1979. A paleoecological analysis of Quadra Sand at Point Grey, British Columbia, based on indicator pollen. Canadian Journal of Earth Sciences 16: 847-858.

Mathewes, R.W., Heusser, L.E., and R.T. Patterson. 1993. Evidence for a Younger Dryas-like cooling event on the British Columbia coast. Geology 21: 101-104.

Mathewes, R.W. and M. King. 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.

Pellatt, M., Hebda, R.J. and R.W. Mathewes. 2001. High resolution Holocene vegetation history and climate from Hole 1034B, ODP Leg 169S, Saanich Inlet Canada. Marine Geology 174:211-226.

Pellatt, M.G. and R.W. Mathewes. 1997. Holocene tree line and climatic change on the Queen Charlotte Islands, Canada. Quatermary Research 48: 88-99.

Palmer, S.L., I.R. Walker, M.L.. Henrichs, R. Hebda and G.Scudder. 2002. Postglacial midge community change and Holocene paleotemperature reconstructions near treeline, southern British Columbia (Canada). Journal of Paleolimnology 28:469-490.

Rosenberg, S.M., I.R. Walker, and R.W. Mathewes. 2003. Postglacial spread of hemlock *(Tsuga)* and vegetation history in Mount Revelstoke National Park, British Columbia, Canada. Canadian Journal of Botany 81: 139-151.

Walker, I. R. and Pellatt, M. G. 2003. Climate change in coastal British Columbia- A paleoenvironmental perspective. Canadian Water Resources Journal 28-531-566

Whitlock, C. and Bartlein, R.J. 1997. Vegetation and climate change in northwest North America during the past 125 kyr. Nature 388:57-61.