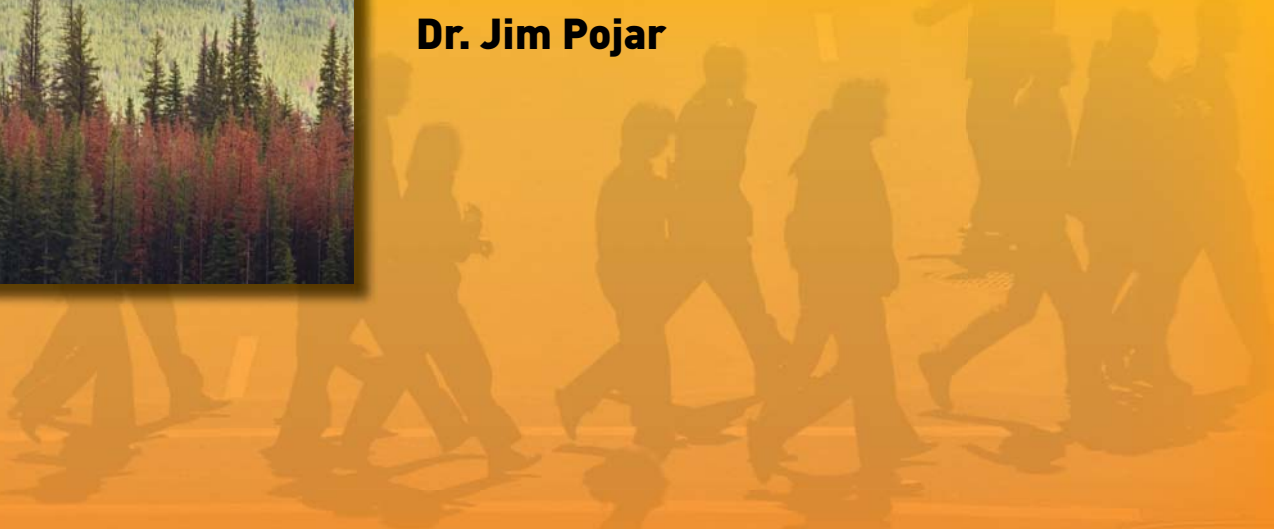


A New Climate for Conservation

Nature, Carbon and Climate Change in British Columbia



Dr. Jim Pojar



Commissioned by the Working Group on Biodiversity, Forests and Climate, an alliance of ENGOs, including:

B.C. Spaces for Nature
Canadian Parks and Wilderness Society
David Suzuki Foundation
ForestEthics

.....

The Land Trust Alliance of B.C.
West Coast Environmental Law
Yellowstone to Yukon Conservation Initiative



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January 2010

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Forest Ecologist Dr. Jim Pojar, who prepared the report, has extensive professional experience in applied conservation biology, forest ecology, sustainable forest management, ecological land classification, and conservation, with a wealth of field experience throughout British Columbia.

The hope is that this synthesis of scientific information (on primarily terrestrial ecosystems) will be an important contribution to the current rethinking of nature conservation and climate action planning in British Columbia. The author and reviewers acknowledge several areas that were not within the scope of this project but would augment our current knowledge. For example, our comprehension of impacts to biodiversity would be greatly enhanced by a deeper understanding and application of Indigenous Ecological Knowledge in B.C. in collaboration with First Nations peoples. Other topics that were outside the scope of the report, but that would be important parts of a comprehensive analysis, include: a socio-economic analysis of the implications of a carbon economy and forest carbon initiatives; a greater understanding of market leakage from conserving forests and reducing harvest levels; implications of genetically modified organisms; and the role of B.C.'s ecosystems, including oceans, in the larger global climate scenarios. A separate executive summary is available at www.landtrustalliance.bc.ca/docs/New Climate for Conservation.

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Introduction



Photo: Aaron Ward

A New Climate for Conservation: Nature, Carbon and Climate Change in British Columbia explores the role of nature conservation in a climate action strategy for ecological adaptation (Part 1) and ecological mitigation (Part 2), with the key recommendation to develop a comprehensive and integrated Nature Conservation and Climate Action Strategy for the Province of British Columbia (Part 3):

Part 1 presents available science on current climate-change projections, and present and future impacts of climate change to ecosystems, species, genotypes, and the processes linking them. The review focuses primarily on forested systems, and also addresses non-forest and aquatic systems. Ecosystem resilience and adaptation options, in relation to climate change, are outlined. Current thinking in conservation science is then summarised in light of external pressures. B.C.'s existing conservation planning and forestry management are reviewed in terms of their ability to respond to the challenges of climate change.

Part 2 summarises literature on natural capital, ecosystem services and the role of ecosystems in climate-change mitigation. Variations in carbon sequestration and storage in different ecosystems are discussed and research gaps in forest carbon dynamics are identified. Current opportunities for an offset market through carbon activities such as avoided degradation, ecological restoration and improved forest management are also explored, in light of recent pilot projects in B.C.

Part 3 integrates the findings from Part 1 and Part 2 in a central recommendation—to develop a comprehensive and integrated provincial Nature Conservation and Climate Action Strategy. To be efficient, this strategy must combine nature conservation and carbon/climate management planning. To be effective, it must embrace the fundamental role of conserving natural ecosystems for adaptation and mitigation of climate change, and for nature's many other ecosystem services, which underpin sustainable options for current and future generations.

Part 1: Biodiversity, Climate Change and Adaptation



Photo: Kurt Hahn

1.1 Importance of British Columbia's Biodiversity

British Columbia is a special place for biodiversity. A full comprehensive review of this importance is found in *Taking Nature's Pulse: The Status of Biodiversity*, prepared by Biodiversity B.C. in 2008.¹ Climate and physiography are the two most important determinants of this biological diversity. The interplay between warm, moist Pacific air and Interior and Arctic air masses occurring over a physically diverse landscape spanning 11 degrees of latitude has resulted in a dazzling array of climates, life forms, and ecosystems.

B.C. is a bio-geographic crossroads, featuring coastal mountains, lowlands, fjords and myriad islands; several parallel mountain ranges, from the Coast-Cascades to the Rockies; extensive plateaus in the southern and northern interior; and the northern portion of the Great Plains (east of the Rockies in the Peace/Fort Nelson region). The province falls within three of the four terrestrial ecoregions in North America, and includes some of the cool oceanic marine ecoregion. It includes elements of the north Pacific oceanic, humid temperate maritime, humid temperate continental, boreal and subarctic plains and highlands, and temperate steppe (grassland) ecoregions. B.C. encompasses landscapes and ecosystems representative of parts of adjacent regions (Oregon, Washington, Idaho, Montana, Alberta, Northwest Territories, Yukon, and Alaska).

B.C.'s ecosystems range from massive coniferous rainforests to high elevation elfin forests and meadows, from hot dry grasslands and shrub-steppe in the southern interior to northern boreal forests and tundra, and include wetland systems as varied as alkaline marshes, peat bogs and cottonwood-dominated river floodplains.

B.C. hosts uncommonly high species richness (*alpha* diversity) for north temperate regions, especially considering its northerly latitudes, the preponderance of rock, ice and snow in much of its landscape, and the fact of Pleistocene glaciation. In addition, there is much between-habitat (*beta* diversity). Forests predominate, covering over 55 percent of the province's total land area, and they include needle-leaf evergreen, deciduous, mixed-wood, and even a bit of broad-leaved evergreen (Georgia Basin) forest types.

B.C. also has extensive grasslands, wetlands, and alplands. In the ruggedly mountainous regions with sharp climatic gradients, the rate of change in species composition (*gamma* diversity) accelerates rapidly from low to high elevations (ocean through forests to alpine in many cases), from south to north, and from west to east, from the wet coast to the dry interior. And all this terrestrial ecosystem diversity is supplemented, enhanced, and connected by the aquatic realm, with its variety and range of freshwater and marine habitats.

The ecological diversity of B.C. is globally significant: 16 biogeoclimatic zones are defined by the Biogeoclimatic Ecosystem Classification (Figure. 1), each with numerous diverse habitats, dry to wet, forested and/or non-forested. Two of these zones are not found anywhere else in the world.²

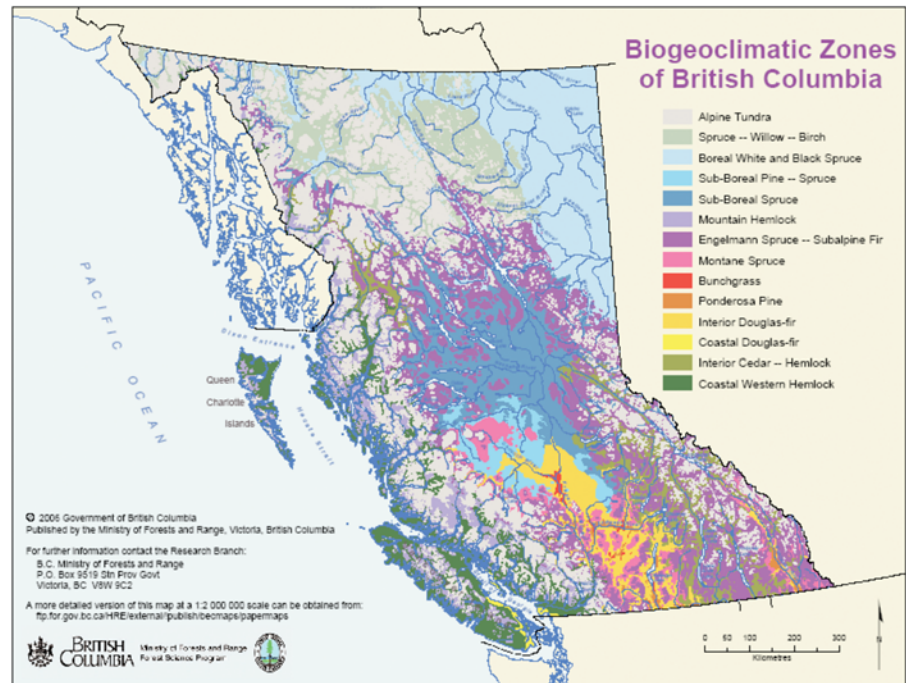


Figure 1. Biogeoclimatic zones of British Columbia. Two additional alpine zones are not shown. Ministry of Forests and Range, 2006.

Not surprisingly, B.C. is the most diverse province or territory in Canada, physically and ecologically, and has the highest number of native species. For example, it is home to 76 percent of our nation's bird species, 70 percent of its freshwater fish, and 60 percent of its evergreen trees. Three-quarters of Canada's mammal species are found in B.C.; 24 of these occur only in this province. The number of at-risk species in the province is also high compared to other jurisdictions of similar latitudes.³

The province currently has global stewardship responsibility for a large proportion of the world's ancient temperate rainforests, wild rivers, salmon and rich marine ecosystems. By hosting a large portion of the world population or range of some species, such as mountain goat (*Oreamnos americanus*) and sooty grouse (*Dendragapus obscurus fuliginosus*), B.C. has a global responsibility for their conservation. The province has also become a globally important refuge for formerly common or widespread species, like grizzly bear (*Ursus arctos horribilis*) and wolverine (*Gulo gulo*). Thus, B.C. has increased international responsibility for species—including several high profile carnivores and ungulates—once widespread across North America but whose ranges have collapsed towards the province.⁴

This concept of global responsibility applies beyond species. B.C. has globally significant biophysical diversity and landscape complexity, as well as internationally significant, dynamic systems like the intact large-mammal predator-prey and wild river-salmon-grizzly bear-forest systems.

“Biodiversity conservation is not, and should not be, a sole question of the number of taxa in an ecosystem; rather, it must also address the maintenance and function of natural ecological and evolutionary patterns and processes in systems as undisturbed as possible.”⁵

B.C.’s globally significant biodiversity highlights include:

- Approximately 60 percent of the province’s original forest remains,⁶ with high proportions of the world’s intact coastal temperate rainforests and Interior wetbelt snow-forests or ‘inland rainforests’.
- Vast intact wilderness areas encompassing entire mountain ranges and large watersheds, with large undeveloped river and lake systems sustaining pristine water quality and aquatic habitat (intact freshwater aquatic habitats are one of the rarest class of ecosystems in the world).
- Glacier-influenced watersheds (those with more than 5 percent of their area covered by glaciers) covering 20 percent of the province, and identified as one of the special elements of B.C.’s biodiversity.⁷
- Intact large-mammal predator-prey systems with continentally important populations of grizzly bear, Stone’s sheep (*Ovis dalli stonei*), mountain goat, woodland mountain caribou (*Rangifer tarandus montanus*), grey wolf (*Canis lupus*), cougar (*Felis concolor*), wolverine, lynx (*Lynx canadensis*), and fisher (*Martes pennanti*).
- Coastal predator-prey systems of peregrine falcon (*Falco peregrinus*) /bald eagle (*Haliaeetus leucocephalus*) and seabirds.
- Major North American flyways with important wetland staging, nesting, and wintering areas for waterfowl and neotropical migrants, along the coast, through interior plateaus and mountains, and the Interior Plains.
- Species for which B.C. has global stewardship responsibility. These include endemic taxa, for example, Vancouver Island marmot (*Marmota vancouverensis*), Newcomb’s butterweed (*Sinosenecio newcombei*), as well as those that have the majority or a large portion of their population or range in the province, for example, mountain goat, Stone’s sheep, sooty grouse, Barrow’s Goldeneye (*Bucephala islandica*), and white sturgeon (*Acipenser transmontanus*).
- Distinctive coastal and intermontane grasslands including the Okanagan Basin—a northern extension of Great Basin-type shrub-steppe and dry forest.
- Globally rare combinations of ecosystems of wet coastal and Mediterranean-type environments with mountain/forest/grassland ecosystems in close proximity, in the Georgia, Nanaimo and Fraser lowlands.
- Extensive island archipelago systems, for example, Haida Gwaii and its endemic biota.

1.1.1 Summary of Biodiversity in B.C.

British Columbia’s dazzling array of climates, landforms and ecosystems represents a natural heritage that is globally significant. From steppe to alpine, tundra to rainforest and mountain wilderness to rich coastal estuaries, these ecosystems provide habitat for assemblages of plant and animal species that are unusually rich for a northern temperate region. British Columbia is home to three-quarters of Canada’s mammal and bird species, 70 percent of its freshwater fish, 60 percent of its evergreen trees, and thousands of other animals and plants.

Some of these species, such as the Vancouver Island marmot, live nowhere else on earth. Some, such as mountain goat and mountain caribou, live mostly in this province. For others, such as grizzly bears and salmon, B.C. has become a globally important refuge as these species have declined precipitously or have been eliminated elsewhere across their historical range. British Columbia also has a global stewardship responsibility for a large proportion of the world’s remaining ancient temperate rainforests, wild rivers and rich marine ecosystems.



Salmon are sensitive to temperature change throughout their life cycle. Photo Robert Koopmans

1.2 Climate Change Underway

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change⁸ asserts with confidence that most of the recent global climate change is due to human activities; the burning of fossil fuels, deforestation, and agriculture have caused increased releases of ‘greenhouse gases’, including carbon dioxide (CO₂), methane, and nitrous oxide. Summaries of the evidence for these conclusions can be found in other publications. Good discussions of climate change and its implications in British Columbia are also available.^{9,10,11,12,13,14} Most recently, the role of emissions from deforestation and land degradation has been better understood by the international community,¹⁵ with a corresponding recognition that reducing these emissions is a key component of an integrated climate action strategy.¹⁶

Although the Earth’s climate changes constantly, the change is not constant; it varies in rate and amplitude. Postglacial climatic history is dealt with extensively in various articles; a short summary is included here.¹⁷ Fifteen thousand years ago, most of British Columbia was covered by ice. The ice sheets melted when the climate warmed between about 13,000 and 10,000 years ago.¹⁸ Deglaciation was accompanied with and followed by rapid warming, then a warm and dry interval, followed by warm moist conditions. About 4,500 years ago, B.C. entered a relatively cool interval that persisted until very recently. Embedded in these millennial trends were shorter periods of warming and cooling, drying and wetting.

The Medieval Warm Period (ca 900 to 1500) was followed by the Little Ice Age (1500 to 1850). Climatic oscillations such as the El Niño-Southern Oscillation and the Pacific Decadal Oscillation also contribute to the variability of B.C.’s climate when considering several-year to several-decade intervals. The overall Northern Hemisphere trend through these oscillations over the past 1,000 years was slow cooling and then rapid warming, starting about 100 years ago, corresponding with rising industrialization and major changes in land use. Observed warming trends in the last century and predicted trends in the future will have increasingly large impacts on British Columbia’s biodiversity, ecosystem services, and greenhouse gas emissions.¹⁹

Global warming and the accompanying changes in precipitation patterns are expected to continue through this century as greenhouse gas concentrations increase.²⁰ The amplitude of expected change cannot

be predicted with precision because of uncertainty about the success of the international community's greenhouse gas reduction efforts. Inevitable errors associated with model projections exacerbate this uncertainty. Initial projections, using several General Circulation Models (GCMs) to provide several different emission scenarios, placed some boundaries around possible future outcomes (Figure 2).

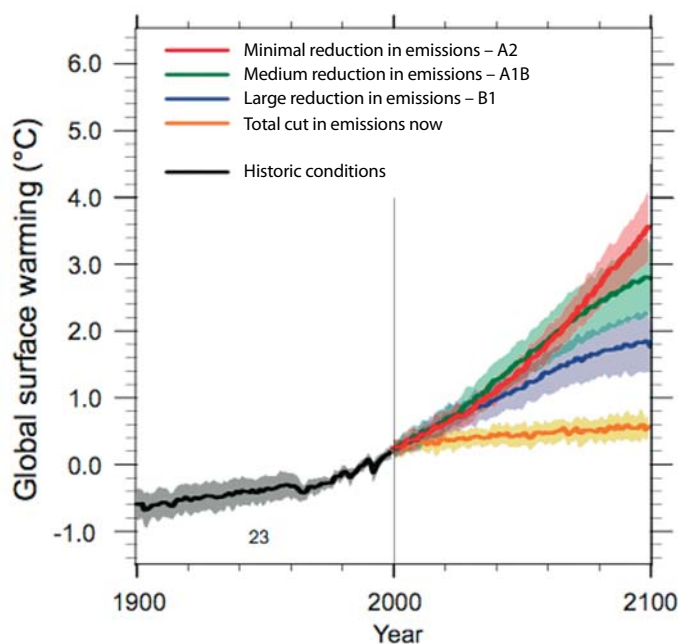


Figure 2. Simulated change in global mean temperature from the 1980-1999 mean value. From 1900 to 2000, the simulation uses past greenhouse gas emissions and natural factors (black line); from 2000 to 2100 it uses selected emissions scenarios (red, green, and dark blue lines). The orange line indicates the effect of an immediate total cut in emissions. Shading around each line represents ± 1 SD on a range of annual means from 16 to 21 GCMs (adapted from IPCC 2007). Retrieved from Spittlehouse (2008).²¹

Recent observations reported by the scientific community at the UN climate talks in Copenhagen, March 2009, confirmed that “given high rates of observed emissions, the worst-case IPCC scenario trajectories (or even worse) are being realized. For many key parameters, the climate system is already moving beyond the patterns of natural variability within which our society and economy have developed and thrived. These parameters include global mean surface temperature, sea-level rise, ocean and ice sheet dynamics, ocean acidification, and extreme climatic events. There is a significant risk that many of the trends will accelerate, leading to an increasing risk of abrupt or irreversible climatic shifts.”²²

1.2.1 Historic and Recent Climate Change in British Columbia

Climatic trends over both the past century and more recent decades indicate major changes in temperature and precipitation in British Columbia, changes that varied by season and by region. Overall, recent measured changes in B.C.'s climate are consistent with, or greater than, predictions from global climate models, confirming the worst case scenarios identified in the March climate talks in Copenhagen.^{23,24}

- The province has warmed up, with winters warming up more than summers.
- The frost-free period lengthened by 21 days between 1950 and 2004.²⁵
- Annual precipitation increased by about 22 percent on average over the past 100 years, with significant seasonal and regional variation. Most of the province experienced reduced winter precipitation and increased summer precipitation over the past 50 years. On the coast, the wet winter season has become shorter but wetter, the dry summer season drier and longer.
- Water temperatures in rivers are rising. For example, peak summer temperatures on the Fraser River's main stem have risen 1.5°C since 1940.²⁶
- Recent warming has probably increased the frequency of large landslides in northern B.C., due in part to melting permafrost and to debuttressing of rock slopes adjacent to retreating glaciers.²⁷

1.2.2 Projected Future Climate Change

The initial modelling of the United Nations Intergovernmental Panel on Climate Change (IPCC) suggested a rise in average surface temperature of Earth in the range of 1.1 to 6.4°C by 2100.²⁸ Given that the worst-case scenarios may occur, it is clear that the resulting future climates will be radically different than what has occurred in the last 750,000 years.²⁹ The problem is exacerbated in northwestern North America because the rate of change increases from the equator to the north pole.³⁰ Climate models project a persistent effect. Excess greenhouse gases already in the atmosphere will continue to drive climate change and its impacts for centuries to come.

The following climate change projections for British Columbia were made prior to the March talks in Copenhagen³¹, and it is clear that the higher end values (worst-case scenarios) are more representative of the trend. Generally, B.C.'s climate over the next 100 years will become even warmer than in the last 100 years, and the rate of warming will be faster. "Associated with this warming will be changes in precipitation regimes and an increased frequency of extreme temperature and precipitation events."³² Overall, as this century progresses, B.C. can expect warmer and wetter winters especially in the north, progressively warmer and probably drier summers in at least the southern half of the province, and initially cooler but ultimately warmer and probably wetter summers in much of the northern half of the province. Winters in general will be wetter across British Columbia, with a greater increase in precipitation in the north, and in many areas the extra precipitation likely will fall as rain rather than snow.³³



While some species, such as mule deer, can disperse and move long distances quickly, many species will not be able to relocate so readily as ecosystems change. Photo Tom Tietz

Future climate change scenarios represent a range of possible climates rather than specific narrow predictions. Moreover, site-specific projections of climate change and its impacts in British Columbia are inherently imprecise because the province has such complex topography and climatic processes, and such sharp ecological boundaries. Nonetheless, scenarios based on the best information currently available suggest that without dramatic changes in human behaviour, B.C. should anticipate the worst-case scenarios. Projections of temperature changes have greater certainty than projections of precipitation changes among the currently available climate models.³⁴ Figures 3 and 4 depict sets of temperature and precipitation projections, summarized below:

Temperature

- Mean annual temperatures warming by 3 to 5°C by 2100.
- January minimums and July maximums rising by 5 to 10°C by 2080.
- Winters warming faster than summers.
- Lakes and rivers increasingly becoming ice-free earlier in the spring, and at least the larger bodies of water freezing over later in the winter.

Precipitation

- B.C. precipitation up 9 to 18 percent by 2100, with most of the increase generally occurring in winter. Also there will be decreasing summer precipitation in the southern half of the province.
- Declining snowpack, in most parts of the province.

- Changing snowpack, with more frequent thaw-freeze events in winter. This will result in denser snow with more crusts and icy layers, and will affect wildlife survival.
- Declining summer stream flows in many snow-dominated systems, resulting in warmer water. Glacier-fed rivers will experience the opposite, for as long as the ice lasts.
- Amplification of the hydrological cycle, manifested by increased cloudiness, latent heat fluxes, and more frequent climate extremes.³⁵ This will increase the risk of drought, heat waves, and intense precipitation events and flooding.³⁶

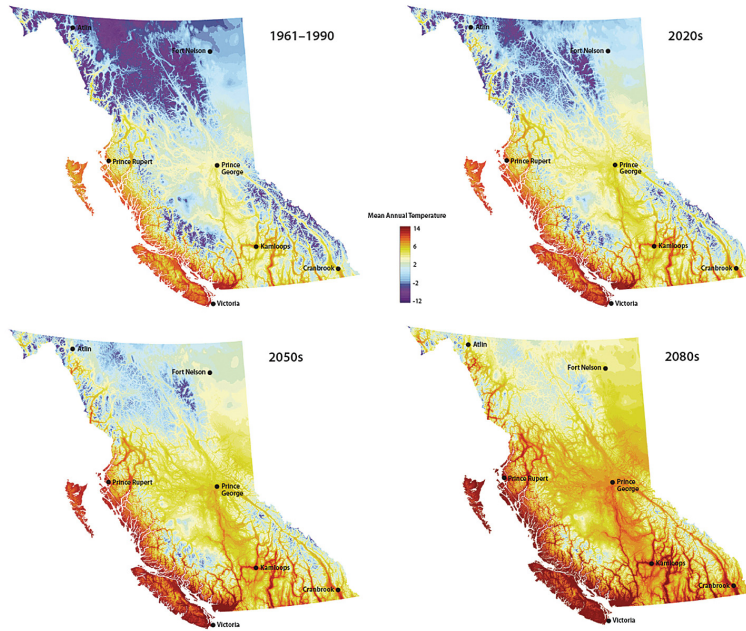


Figure 3. Mean annual temperatures for British Columbia: past ‘normals’ (1961-1990) and projections for 2020s, 2050s, and 2080s, for the middle range A2 scenario from the Canadian Global Climate Model version 2 (CGCM2). Retrieved from Spittlehouse (2008).³⁷

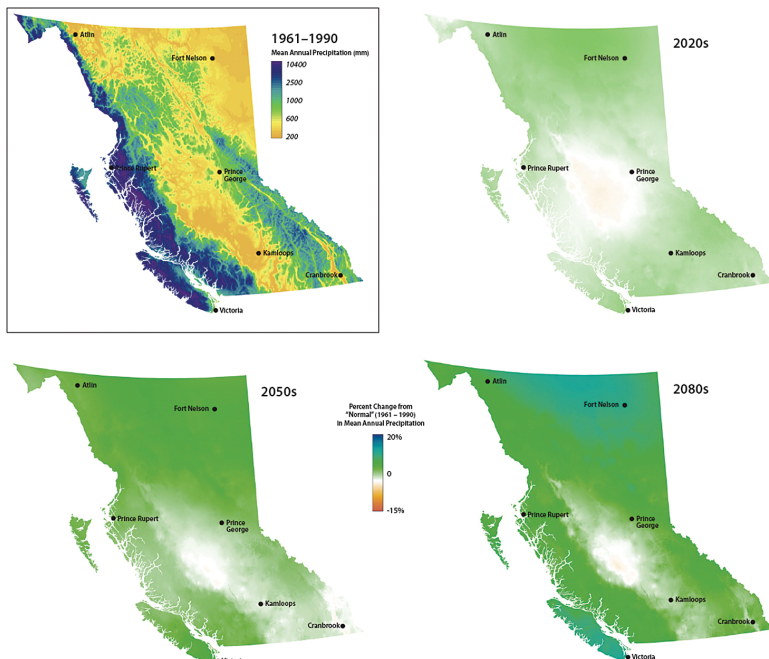


Figure 4. Annual precipitation for British Columbia: 1961-1990 baseline & projected percentage changes from baseline for 2020s, 2050s and 2080s, for A2 scenario of CGCM2. Retrieved from Spittlehouse (2008).

1.2.3 Summary of Climate Change Underway

Global climate change is underway. Significant warming has already occurred on land and in water, and the continuing changes are expected to happen faster and be more pronounced in British Columbia than the global average. British Columbia's climate over the next 100 years will become even warmer with mean annual temperatures warming by 3 to 5°C if current trends continue unabated. There will be more extreme weather events with increasing intensity of storms, floods, wildfires and drought. As this century progresses, B.C. can continue to expect warmer and wetter winters especially in the north, progressively warmer and drier summers in the southern half of the province, and wetter initially cooler but ultimately warmer summers in much of the northern half of the province.

1.3 Impacts of Climate Change on B.C.'s Biological Diversity

Climate change is already significantly impacting healthy ecosystems in British Columbia, and will likely cause more dire consequences for fragmented or degraded ecosystems. The changing climate is stimulating species-level changes in range and abundance, life cycle and behaviour, and genotypes. Globally there is evidence that some species are already evolving (adapting genetically),³⁸ or expanding their range polewards or upwards in elevation³⁹, or adjusting migration,⁴⁰ breeding,⁴¹ or flowering⁴² times in response to climate warming. Species-level changes are resulting in changes to ecosystems.⁴³ These and other inter-related changes to ecological processes, ecosystems and species are also happening in British Columbia.

1.3.1 Review of Changes in Ecological Processes, Ecosystems and Species

- Warmer winters and longer growing seasons, as well as suppression of forest fires, have been linked to the current vast mountain pine beetle (*Dendroctonus ponderosae*) epidemic.^{44,45,46,47} The intensification of fungal needle blight (*Dothistroma septosporum*)⁴⁸ on lodgepole pine⁴⁹ can also be attributed in part to climate change.
- Native willows are under attack by an introduced insect pest, the willow stem borer (*Cryptorhynchus lapathi*),^{50,51} a Eurasian weevil that has spread widely in southern and now central B.C.—especially in the past 30 years—and is heading north along highways and logging roads. The recent rapid spread appears to be related to climate warming. Attacked willows tend to suffer repeated attacks; the weevil population builds up in individual stems and then spreads to adjacent willows. More than 75 percent of the willows in some areas have been attacked. Ecosystem consequences are unknown but willows are used by many different animal species and play key ecological roles in wetlands, riparian habitats, and upland forest and shrublands.
- Extensive die-back and changing phenology of trembling aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) in the southern interior⁵² are having an impact on the ecosystems they inhabit.⁵³
- Yellow-cedar (*Chamaecyparis nootkatensis*) dieback has a climate change component. The decline of yellow-cedar in Southeast Alaska and on B.C.'s north coast appears to be due to a type of freezing injury to roots. Susceptibility of the tree roots to freezing damage is related to decreased protective snowpack and premature 'dehardening' in the spring.^{54,55,56} This could be an example of a general phenomenon: climate warming paradoxically may actually increase the risk of frost damage to plants.⁵⁷ Mild winters and warm early springs can induce premature plant development, resulting in exposure of tender parts to subsequent late-season frosts, as evidently happened in spring 2007 in the eastern USA.⁵⁸
- Dieback of western redcedar (*Thuja plicata*) has recently been reported from the south coast, especially on the east side of Vancouver Island—presumably because of increasing drought stress.⁵⁹
- Populations of eight bird species, including the common loon (*Gavia immer*), two surf scoter species (*Melanitta fusca* and *M. perspicillata*), sandhill crane (*Grus canadensis*), Wilson's phalarope (*Phalaropus tricolor*), Lewis' woodpecker (*Melanerpes lewis*), Swainson's thrush (*Catharus ustulatus*), and yellow

warbler (*Dendroica petechia*), were found to have earlier arrivals, later departures, and extended ranges northward.⁶⁰

- Warmer, wetter springs in west central B.C. could be at least partly responsible for reduced nest area reoccupancy and breeding success of goshawks (*Accipiter gentilis*). Increased precipitation is linked to a decrease in prey abundance, and warmer spring temperatures are associated with high rates of mortality as a result of attacks on nestlings by black flies.⁶¹
- Recent reduction in populations of Fraser River sockeye salmon (*Oncorhynchus nerka*) has been linked in part to increasing river temperatures and changes to the flow regime.⁶² In the hot, dry, low-flow summer of 2004, Fraser River temperatures reached 20-21°C, about four degrees warmer than normal and into the lethal range for sockeye.⁶³ Soon salmon may be unable to migrate through the Fraser due to overly warm waters.
- In October 2008, many populations of Pacific sockeye salmon were placed on the IUCN Global Red List of Threatened Species. One-quarter of the world's sockeye salmon populations are at risk of extinction, including 10 B.C. runs. Key threats to threatened/endangered populations included mixed stock fishing leading to overfishing of smaller, less productive stocks, negative effects of hatcheries and artificial spawning habitat, and “changing river and ocean conditions that are likely linked to global climate change, expressed in poor marine survival rates and increased incidence of disease in adult spawners.”⁶⁴
- Earlier snow melt, warmer temperatures, and more frequent drought stress have created a longer fire season in much of inland western North America, resulting in an increase in the number, size, and intensity of wildfires.^{65,66,67}
- B.C. is experiencing more extreme events in general, with increased damage from storms, floods, erosion, droughts, wildfires, and more frequent and extensive outbreaks of pests such as bark beetles, needle and leaf diseases, and defoliating insects.

1.3.2 Summary of Climate Change Impacts

Climate change is already significantly impacting healthy ecosystems in British Columbia, and will likely cause more dire consequences for fragmented or degraded ecosystems. Changes in species range and abundance, life cycle and behaviour, survival rates and genotypes have all been detected and have ongoing effects on ecosystem structure and function. Impacts have occurred at all scales, from the dramatic impacts of mountain pine beetle populations on vast areas of forests, to dieback of single species. Other types of change, such as the arrival/departure dates of migrating species, and impacts on insects and the food webs they support, are all being witnessed.

1.4 Projected Impacts of Climate Change on B.C.'s Biological Diversity

Climate is the chief determinant of the distribution of species and the nature and character of ecosystems, and thus is a key driver of biodiversity. Over at least the past 4,000 to 4,500 years, British Columbia has had a relatively stable climate, leading to the current pattern of ecosystems.⁶⁸ The anticipated impacts of climate instability and change on B.C.'s biodiversity are diverse, complex and not well understood. Figure 5 presents a good framework for thinking about how and why biodiversity will be affected and could respond, at ecosystem, species, and genetic levels.

1.5 Future Ecosystem Responses

Climate largely determines the nature and distribution of terrestrial species and ecosystems, and through its effects on the water cycle also plays a major role in freshwater aquatic ecosystems. Climate change is already driving worldwide ecosystem change in structure (vegetation and species composition), function

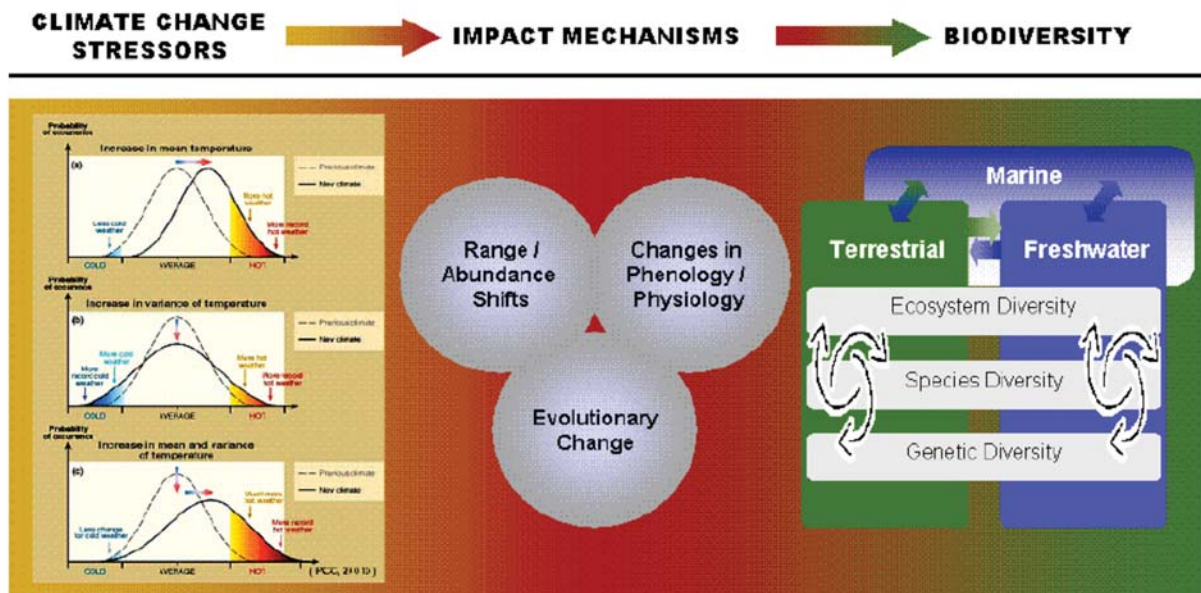


Figure 5. Conceptual framework of climate change impacts on biodiversity. Retrieved from Compass Resource Management (2007).⁶⁹

(productivity, decomposition, water and nutrient cycling), processes (disturbance regimes, successional pathways and hydrological regimes), and distribution.^{70,71} Future responses of B.C. ecosystems will be complex, and are difficult to predict because they will reflect the combined effects of changing climate, land- and resource-use activities, and invasive species.

Two principles should guide the interpretation of projected ecosystem trends and impacts:

1. Ecosystems do not migrate, species do.

Ecosystems will not move *in toto* to more northerly latitudes or aspects, or upward to newly suitable climate envelopes. Ecosystem change will result from changes in distribution at the species level. Existing ecosystems will lose some species, gain others, and experience changes in abundance and dominance of the species that persist. Species are responding ‘individually’ to environmental change. Some species will stay put and their populations will either wax or wane depending on changing circumstances. Other species will move, if they can, to suitable habitats elsewhere, and will reassemble most likely in different combinations, including some novel ones. Some species will move in close concert; for example, hosts and their parasites, and prey and their specialized predators. Some close partners, like flowering plants and their insect pollinators, or trees and ectomycorrhizal fungi, could become at least temporarily ‘decoupled’ during long-distance migrations. Weedy ectomycorrhizal fungi, that might fill vacated niches, can be parasitic and facilitate the invasion of exotic weedy plants. New arrivals will interact with persisting species, and with exotic immigrants, to create new ecosystems with new structures and functions.

2. Most species cannot move fast enough to keep up with the projected changes.

The potential geographic range, or potential niche, of many species will shift markedly or expand greatly, but species that migrate slowly, like many of our trees, will need decades and probably centuries to move accordingly or to realize their niche.⁷² Long-distance dispersal will play a key role, as it has in the past.⁷³ Species with poor dispersal capabilities, like flightless beetles, could fail to move quickly enough to survive at the local level. Species whose potential geographic range shrinks could ultimately disappear if reproductive individuals die-off *en masse* (perhaps done in by a pathogen or an extreme disturbance or weather event) and environmental conditions are no longer suitable for their progeny or younger generations.

If the future climate turns out to be an analogue of the relatively recent past—the Xerothermic Interval of the

Holocene (between 10,000 and 6,000 years ago)—when climates were 2 to 3°C warmer than at present, we can expect some general vegetation trends toward conditions that prevailed at that time. Increases in weedy, drought-tolerant, and alkali-tolerant species, and decreases in moisture-loving and acid-tolerant species can be expected⁷⁴—at least in southern B.C., where the climate will probably become drier as well as warmer and where the recent fossil record is fairly well documented.^{75,76}

1.5.1 Changes to Terrestrial Biogeoclimatic Zones

Changes to B.C.'s ecological (biogeoclimatic) zones were first projected by Hebda⁷⁷ in 1997, more recently by Hamann and Wang⁷⁸ in 2006 (Fig. 6), and in the most recent draft analysis by Wang, Campbell and Aitken for 2009.⁷⁹ Climate envelope modelling shows the future climatic niche of these different biogeoclimatic zones, not necessarily where species or ecosystems will be in the future. The most recent projections were done using “best,” intermediate and worst-case scenarios. As previously indicated, the worst-case scenarios are becoming the most likely (3 to 5°C in 70 to 100 years), ‘forcing’ a shift of today’s ecological zones (or rather, the climate envelopes for such zones) a predicted 900 to 1500 m up in elevation and 450 to 750 km north. The rate of projected ‘climate envelope shifts’ is estimated to be at least 40 km per decade. Suitable habitats will shift too fast for many species to keep up, or to compensate through dispersal and migration.

General predicted changes in the zonal climate envelopes include the following:

- A general shift of zones from the southern to the northern half of B.C.
- A major expansion northward and upslope of dry non-forest (grasslands, shrub-steppe) and dry forest zones (especially in the interior but also on the south coast).
- A massive expansion of moist coastal and interior conifer forest zones upslope and north at the expense of subalpine and sub-boreal spruce zones.
- A major decline in cordilleran boreal (spruce) zones in central and northern B.C.
- A near disappearance of northern subalpine/subarctic spruce-willow-birch bioclimates.
- A wide-ranging change in wetlands and aquatic ecosystems because of warmer water and changes in hydrology related to decreased snowpack and shrinking glaciers.
- A shrinking of alpine tundra ecosystems and disappearance of alpine ‘islands’ as woody ecosystems (subalpine forests and shrublands) shift up in elevation. Some of the worst-case scenarios project subalpine conditions into much of the province’s alpine environment.
- Large diebacks of trees, including further diebacks of aspen, paper birch, ponderosa pine (*Pinus ponderosa*), and whitebark pine (*Pinus albicaulis*), are expected due to drought and drought-facilitated insect, disease and fire damage.⁸⁰

Dramatic expansions are indicated for the potential area of the Interior Cedar-Hemlock (ICH), Bunchgrass (BG), Ponderosa Pine (PP), Interior Douglas-fir (IDF), and Coastal Douglas-fir (CDF) zones.^{82,83,84} The Engelmann Spruce-Subalpine Fir (ESSF), Ponderosa Pine, and Interior Douglas-fir bioclimates will probably exhibit the largest northward shifts. Major declines are projected for the climate envelopes of the Alpine Tundra (AT), Mountain Hemlock (MH), Montane Spruce (MS), Sub-Boreal Spruce (SBS), Boreal White and Black Spruce (BWBS), and Spruce-Willow-Birch (SWB) zones.^{85,86} The largest areal changes in climate envelopes are projected for the ICH zone, which may double in size, and for the AT and SWB zones, which may decrease by more than 90 percent.

Given these projections, “the ecological and species range adjustments suggested by models will take many decades if not centuries... The rates of migration and spread of the species required for such large expansions over such great distance prohibit anything like the modern zones to develop in this interval. Transient ecosystems of undetermined composition must be expected. The character of these will likely be mediated by pest outbreaks and fire.”⁸⁷ Such landscape-scale disturbances and extreme events like summer droughts, spring frosts, fierce storms and floods could be the determining factors.

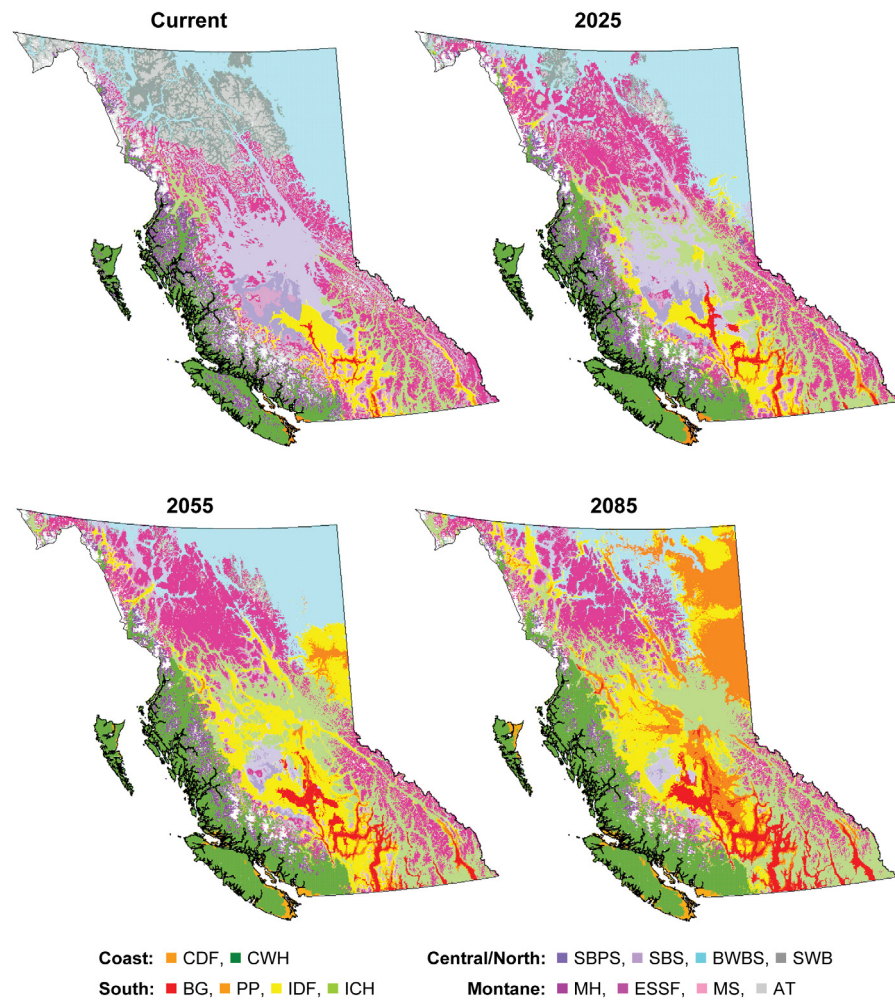


Figure 6. Potential shifts in distribution by 2025, 2055 and 2085 of the existing climate envelopes of British Columbia's biogeoclimatic zones. Changes projected by modelling the contemporary climate parameters of the zones in terms of predictions under an average climate change scenario (CGCM1gax). Retrieved from Hamann and Wang (2006).⁸¹ The updated Wang, Campbell and Aitken maps were not available at time of printing.

Other potential changes to B.C.'s ecosystems

- In northern B.C. it is more likely that subalpine shrublands ('buckbrush') rather than forest will occupy what currently is the lower alpine zone—as is already happening in the tundra of the north slope of Alaska/Brooks Range⁸⁸—partly because the shrubs have shorter generation times, can reproduce through suckers, and can migrate faster than coniferous trees.
- Forest composition (tree and understory species, including bryophytes and lichens on the forest floor) will change significantly. Expect an expansion of dry forests in the southern and central interior, with moister warmer forests in the north.
- The Alpine bioclimate is expected to diminish throughout the province although this trend will probably be geographically idiosyncratic, not monolithic.⁸⁹
- Wetlands are physically constrained systems, sensitive to changes in hydrology, geomorphology, and nutrient budget, and in most of the province are patchy and insular in distribution. Consequently they are vulnerable to climate change.⁹⁰ Fossil studies suggest that shallow interior wetlands, especially of climates that are already dry, could dry up more.⁹¹
- Wetlands of cool moist climates and stable hydrology, such as bogs, are likely to be negatively impacted. Marshes and rich fens with fluctuating water tables and higher levels of nutrients are more likely to persist.⁹² Changes in wetlands will affect not only obligate wetland species—like waterlilies, dragonflies and muskrats—but also will have major consequences for the breeding and migration of birds.⁹³
- The climate envelope of the now nearly continuous grasslands of southern interior B.C. could expand substantially, throughout valley bottoms and up lower slopes, perhaps as far north as Quesnel.^{94,95,96}



The glaciers of Glacier National Park have retreated significantly in recent decades.

Photo Amar Veluri

But they will probably be ‘mongrel’ or ‘weedy’ grasslands, infested with alien invasive species, as many contemporary grasslands already are in southern B.C.

- In contrast, boreal grasslands could be at high risk of decline in wetter warmer climates, unless increasing temperatures overwhelm increasing precipitation. These grasslands are already rare in the landscape and are currently being invaded by woody vegetation. Perhaps they will persist only on the driest south-facing sites, and maybe only if humans augment the woody-plant-eating activities of beaver (*Castor canadensis*), moose (*Alces alces*), Rocky Mountain elk (*Cervus elaphus nelsoni*), mule deer (*Odocoileus hemionus hemionus*) and Stone’s sheep with prescribed fire. It is uncertain as to what will happen in northern B.C. to the mesic subalpine grasslands of high wide valleys with double treelines. They too could decline if shrubs (willows, *Salix* spp., and shrub birch, *Betula nana*) expand, but it could remain cold enough at high elevations to maintain the cold air ponding that is partly responsible for such patterns.
- Province-wide, 40 to 60 percent of B.C.’s glaciers will disappear and others will diminish greatly, leaving behind big areas of deglaciated terrain as fresh substrate for colonisation and ecological succession. Succession and community assembly will be a stochastic-deterministic process. Some outcomes will be along the lines of those that have already been documented^{197,98,99,100} but others will probably be novel and difficult to predict.
- Permafrost melting in northern peatlands will lead to accelerated decompositions of ‘deep carbon’ deposits with large positive feedbacks to atmospheric CO₂.¹⁰¹
- Very little is known about impacts of climate change on soils in B.C. Soils are living systems, with far greater species diversity than aboveground, and soil biology will likely present an important limitation to plant migration. There is growing evidence that changes in soil biology can cause ecosystems to collapse to an alternative regime that will hinder migration of species (other than weeds.)¹⁰²
- More ‘trophic mismatches’ (that is, decoupling of species and ecosystem processes) could develop as plant phenology advances with a warming climate. For example, herbivores (including large ungulates) currently may base their reproductive cycles or seasonal migrations on day-length, while vegetation emerges in the spring more as a consequence of local temperatures. As local temperatures increase and vegetation leafs out earlier in the season, successful herbivore reproduction might decline—as it evidently has in Arctic caribou.¹⁰³ However, some species that have been transplanted to southern latitudes have adapted quickly.¹⁰⁴
- B.C.’s current biodiversity will increasingly persist in, or come to, the mountains for sanctuary and survival. In mountainous terrain with steep climate gradients and extremely active hydrogeomorphological processes, species and ecosystems are highly sensitive to changes in climate and disturbance regimes. Rapid change presents both challenges and opportunities in these uncompromising

environments, which represent a provincial hallmark. In North America, a 100-m rise in elevation is roughly equivalent (ecologically) to travelling north 1 degree of latitude. Mountain and valley systems provide the best opportunities for biodiversity conservation—beyond the typical north-south and east-west opportunities for species migration, mountains also offer up-down altitudinal and ‘contouring around the mountain’ avenues for migration.

“The elevational compression of biomes causes mountains to become hot spots of biological diversity... This compression of life zones explains why, on a 100 km grid scale, no landscape can beat the biological richness of mountains. Nowhere else is it possible to protect and conserve so much biological diversity within a relatively restricted region, than in mountains ...”¹⁰⁵

1.5.2 Natural Disturbances

Natural disturbances are fundamental to ecosystem structure and function.¹⁰⁶ Recurrent disturbance and recovery “within ecosystems is an important mechanism for energy flow and nutrient cycling, and for maintaining age, species, genetic, and structural diversity, all attributes of ecosystem health.”¹⁰⁷ But now climate change is pushing natural disturbance regimes beyond the historical range of natural variability.^{108,109} The increased frequency and/or intensity of disturbances will affect the structure and function of all ecosystems. Interactions, feedbacks and synergies among natural disturbances, land uses, invasion of non-native species, and vector-borne diseases, among others, will exacerbate the effects of climate change. Many B.C. ecosystems, such as lodgepole pine forests, boreal spruce forests, forest streams and riparian systems depend on periodic fire, insect outbreaks, debris slides, or floods and other disturbances for renewal and maintenance of ecological integrity. As major agents of change in the coming decades, shifting disturbance regimes and patterns could become as important as increasing temperature and changing levels of precipitation.¹¹⁰

1) Insects and diseases

Insects and fungal disease will continue to play major roles in forest dynamics. Major agents of disturbance and change include bark beetles, for example, mountain pine beetle, spruce beetle (*Dendroctonus rufipennis*), and Douglas-fir beetle (*Dendroctonus pseudotsugae*); foliage insects, for example, spruce budworm (*Choristoneura occidentalis*), western hemlock looper (*Lambdina fiscellaria lugubrosa*), and forest tent caterpillar (*Malacosoma disstria*); and fungal diseases (for example, *Dothistroma* needle blight, stem rusts, and root rots). Insects and diseases in general are very adaptable and could respond to environmental change faster than their long-lived hosts;¹¹¹ range expansions, contractions and shifts, and an increase in the number and variety of forest pests all can be anticipated as the climate warms.^{112,113} Pest outbreaks are expected to increase, and to increasingly influence the trajectories and outcomes of change, as forests disassemble, reassemble, and follow a variety of successional pathways.

Willows will continue to decline as the willow stem borer spreads upward and northward and intensifies its attacks. We still don’t know to what extent the willows will recover. Many of them can resprout from the stem or the base, but the new shoots appear to be of poorer quality than those produced after ‘normal’ mechanical damage or browsing. And the diseases that follow the weevil into the stems can kill the shrub outright. Ecosystem consequences are also unknown but could be huge: think of the potential impacts on moose, beaver, snowshoe hare (and therefore lynx), grouse, songbirds (especially the neotropical migrants that seem to depend on willow thickets). The damage could alter the ecological role of willows in wetlands, riparian habitats, and upland forest and shrublands. It is also possible that other shrubs—such as alders (*Alnus incana*

tenuifolia, *A. viridis*) and scrub birch, which generally speaking are less valuable for wildlife, could increase at the expense of willows.

2) Fire

We can expect more wildfires, larger areas burned, increased fire severity, and increased length of the fire season.¹¹⁴ While southern and central B.C. are expected to get warmer and drier in the summer and experience more frequent, severe, and extensive fires, northern B.C. is more likely to become wetter¹¹⁵ and thus could experience a decrease in fire frequency. Fire will probably continue to be a rare event on the wet coast.

3) Mass movements

Permafrost will continue to melt. This will result in more frequent earth slumps and landslides in terrain with permafrost. Northern B.C. has scattered discontinuous permafrost, most often found in bogs and other peatlands, on north slopes, and more generally at high elevations. Counterintuitively, such mass movements may increase local and regional biodiversity because they add site, soil and habitat diversity to the landscape, with corresponding increases in species diversity.¹¹⁶ These impacts will be amplified by existing disturbances. Logging and extensive road building have substantially increased the frequency of landslides throughout the logged parts of the province.¹¹⁷ Soil disturbances caused by logging, mining, and natural gas exploration and development, and the associated resource roads, facilitate the spread of exotic invasive species.

4) Wind

Large-scale, catastrophic forest blowdown has, historically, been relatively rare in B.C., with return intervals of 300 to 500 plus years.^{118,119} Windstorms are more frequent on the coast than in the interior, and the tree mortality due to wind events also varies regionally, ranging from up to 80 percent in affected stands of wet coastal forests to less than 15 percent in interior Ponderosa pine forests.¹²⁰ Disturbance regimes of wet coastal forests are currently dominated by fine-scale gap dynamics, with frequent events that affect only small numbers of trees.^{121,122} Climate warming will increase the intensity of atmospheric convective processes and thus the frequency and intensity of windstorms.

Northern Vancouver Island, areas of the central and northern B.C. mainland coast, and parts of Haida Gwaii are most susceptible to big blows. Frequency of catastrophic blowdown could increase to approximate wind disturbance regimes in parts of southeast Alaska. Large windthrow events there can have return intervals of less than 300 years, can dominate the disturbance regime, and are a major determinant of forest structure.¹²³

Windstorms are often accompanied by increased precipitation, a combination that can destabilize soils and increase the frequency of landslides.¹²⁴

5) Invasive species

The most significant overall trend in ecosystem structure could be increased dominance by opportunistic species that do well in changed environments or disturbed habitats.¹²⁵ In other words, pioneering and early successional native species, and weedy invasive non-native species.^{126,127} Because invasive species lack natural enemies in their new environment, they often spread rapidly and can behave aggressively, or infiltrate and



Mountain goats will increasingly encounter species of lower elevations moving into traditional alpine habitats.

Photo Jason Puddifoot

occupy both disturbed and undisturbed habitats. They often change the structure and function of ecosystems by out-competing native species and by altering nutrient cycles, natural disturbance regimes, and trophic interactions.^{128,129,130}

The 18 or so species of European earthworms¹³¹ invading B.C.'s forests, which since Pleistocene glaciation have retained a very few native species of earthworms,¹³² show how introduced species can profoundly change ecosystems.¹³³ These earthworms have changed the way nutrients cycle, leading to a change in community composition and reducing abundance of understory plants.^{134,135} Alien species are already a big problem in much of the province, being highly aggressive and adaptable, while new alien species continue to be introduced.^{136,137,138}

6) Disturbance interactions and uncertainty

Historical studies and models have improved our understanding of projected climate change impacts on individual natural disturbance types. Interactions among disturbance types, and between natural and human-caused disturbances, are more difficult to forecast.¹³⁹ Under rapid climate change, the dynamics and impacts of compounded disturbances are likely to be unpredictable and could be unprecedented.

More frequent and severe wind disturbance is likely to induce structural stress in trees, facilitating infection by heart or butt rot fungi, and in turn increasing forest susceptibility to further wind disturbance.¹⁴⁰ Similarly, more frequent drought can render trees more susceptible to disease outbreaks, which can temporarily increase the probability of fire. Research on impacts of mountain pine beetle outbreaks on fire suggests that dead needles in the tree crowns result in a higher probability of fire crowning, faster rates of fire spread, and increased fire intensity, as well as more long-range spotting—but only as long as the needles stay on the dead trees. Once the dead needles have fallen, dead stands of pine are no more likely to burn than live.¹⁴¹ By the time the dead pines fall down, fire hazard will have decreased, but if fire does break out, surface fire would be more intense and crowning in the remaining live tree canopy would be more probable.¹⁴²

Human land-use activities often have a synergistic interaction with natural disturbances. Decades of fire suppression coupled with climate warming have been implicated in the current huge outbreaks of mountain pine beetle.¹⁴³ The collective consequence of reduced mortality and shortened life cycle of beetles, and the increased area of climatically and demographically susceptible pine forests, set the system up for a beetle outbreak and perhaps even for a fundamental regime shift. Regime shifts occur when a system's resilience is exceeded.¹⁴⁴ The conifer-bark beetle/microbial symbiotic system includes key elements often associated with regime shifts: cross-scale interactions, positive feedbacks, multiple causalities, critical thresholds, sensitivity to external drivers.¹⁴⁵ Other unprecedented regime shifts are predicted in the coming decades.

The combination of long-term fire suppression, wholesale planting of lodgepole pine, and moister summers has intensified *Dothistroma* epidemics in northwestern B.C.¹⁴⁶ The current decline of whitebark pine in high-elevation forests provides an excellent and sobering example of the ripple effect of climate change on disturbances. Whitebark pine is not regenerating very successfully these days because of a) widespread mortality of young trees due to the introduced white pine blister rust (*Cronartium ribicola*), b) beetle-caused mortality of cone-bearing trees, c) fewer fires that normally provide suitable sites for seedlings.^{147,148,149}

Warmer temperatures at high elevations have enabled mountain pine beetle outbreaks to spread up into parts of the whitebark pine's range where they had not occurred before.

1.5.3 Ecosystem Productivity

Several factors could contribute to increased ecosystem productivity. If moisture is adequate, plants grow faster at warmer temperatures and with elevated levels of atmospheric CO₂¹⁵⁰—but only up to a point. For example, tree species have temperature optima above which growth rates level off or decline.^{151,152,153,154}

Available nitrogen can become a limiting factor in a CO₂-enriched environment.^{155,156} Because plants exposed

to relatively high levels of CO₂ can partially close their stomata, thus reducing water loss and lengthening their growing season,¹⁵⁷ longer warmer summers with more CO₂ could also result in more growth. Gains in aggregate yield of tree biomass could, however, be offset by nutrient limitations, maladaptation to changing environmental conditions,¹⁵⁸ and losses due to other factors related to climate change, including increased fire, insect and disease outbreaks, severe weather events, thaw-freeze damage, and increased moisture stress in some parts of the province.^{159,160,161}

Projected effects of climate shifts on productivity vary among regions of British Columbia, they also vary according to the modelling approach used. Wetter coastal ecosystems could benefit from a longer growing season. Drier ecosystems in the southern interior and along the south coast are likely to experience increased drought and decreasing productivity. Ecosystem productivity could increase in the north and at high elevations, where cold air and soil temperatures and short growing seasons currently limit plant growth. In such energy-limited environments, warmer temperatures combined with increased CO₂ should result in longer growing seasons, higher rates of photosynthesis, and increased primary production, decomposition, and rates of mineral cycling.¹⁶² However, unsuitable conditions for regeneration (for example, lack of mineral soils in high mountains and northern muskeg), slow migration, and other factors such as nutrient limitations will likely retard the emergence of productive forests in these regions.¹⁶³

1.5.4 Freshwater Aquatic Ecosystems

The implications of climate change for freshwater biodiversity are not certain, with strong variation expected among watersheds—but clearly lake and stream ecosystems and their dynamics will change.^{164,165} Habitats and species of concern in aquatic systems are those susceptible to climate warming, such as:

- cold-water habitats;
- cold-water species, for example, salmonid species;
- high altitude systems;
- small shallow lakes;
- small connecting streams.

Not surprisingly, fish have received considerable attention to date.^{166,167} Climate change will alter the distributions of freshwater fish in B.C. through changes in water temperatures, precipitation, streamflow, and introduction/invasion of non-native species.¹⁶⁸ Warming rivers, lakes and the ocean will continue to impact populations of salmon and other fish species by influencing the timing of migrations, the availability of food, and the habitat suitability of river systems.¹⁶⁹ Changes in runoff and other streamflow characteristics are anticipated and could affect spawning habitat, either through erosion and sedimentation during peak flows and floods, or through exposure during low flows.¹⁷⁰ Fewer salmon returning to B.C.'s rivers will reduce the food resource for consumers such as bears and bald eagles, resulting in ecosystem-level impacts on nutrient cycles and forest food webs.¹⁷¹

More frequent drought and extended summer low-flow periods are expected in some rainfall-driven systems, further increasing water temperature, modifying ecosystem structure and function and favouring warm-water species. The timing and intensity of freshet floods will change in streams fed by melting snow or glaciers. Some such systems could eventually become rainfall-driven, rather than glacier melt or snowfall dependent, a hydrological transformation with large ecological impacts.

Lakes and ponds are also very sensitive to temperature changes. Many lakes have a characteristic cycle of thermal stratification that sets up in the summer and turns over in the fall, mixing nutrients and oxygen in the water column. This fundamental dynamic will be altered as water temperatures increase and as winter ice diminishes.¹⁷² Paleoecological studies indicate that the composition of lake biota is also a function of water temperature. We can expect increasing compositional changes in the coming decades, as well as trophic mismatches and the resultant changes in system function.¹⁷³ Moreover, some small lakes could become

smaller and shallower, or even dry up as the climate warms, resulting in changes to shoreline and aquatic communities.¹⁷⁴

Aquatic conditions depend on past glacial history and future climates. Fish species are still undergoing a postglacial expansion into northern B.C. and the Yukon. Landforms and the relationship between land and water created by the glaciers determine current fish habitat. There are a variety of lakes with different characteristics, including shallow depositional lakes. With climate change, such shallow lakes will warm to the point that certain fish species no longer will be able to survive in them.

Beyond the changes in the timing and amount of the spring melt and peak flows, warming is also expected to accelerate the water cycle (increasing rates at which water enters the atmosphere and rains or snows down again). The effects of this on hydrology, fish and invertebrate populations remain to be seen. Freshwater systems are constrained by topography; freshwater aquatic species have limited migration options because their habitat is within the lake/stream system.

Changes in water temperature could affect fish populations dramatically. For example, there is evidence (noted above) that suggests salmon may soon be unable to migrate through the Fraser River due to overly warm waters.¹⁷⁵ On the other hand, salmon returns to the Mackenzie River could increase, allowing the fish to reach the upper Liard River system in B.C. Pacific salmon are known to occur to a limited degree in Canadian Arctic waters, with reports of pink, chum, sockeye, and coho in decreasing order of frequency. Stray salmon continue to turn up in the catches from domestic and subsistence fisheries in the Arctic; the Gwich'in Renewable Resource Board (Inuvik) confirms that salmon have been caught in the Mackenzie River delta, as well as upriver near Arctic Red River, Norman Wells, and in the Peel River.¹⁷⁶

Glacial recession is ongoing and continues to create new habitats. Receiving waters have high turbidity (cloudiness due to suspended sediments) and lower productivity. Over time, the yield of water from non-glacial rivers could increase or decrease, depending on precipitation trends, whereas the yield from glacial rivers is already increasing and there is an ongoing contraction of spawning habitat for some species. Some other rivers become more suitable for spawning as water levels drop. Larger streams will sustain spawning habitat over such change. Small creeks are most at risk from falling water levels. Eventually even glacial rivers will have reduced flows as the ice melts away.¹⁷⁷

1.5.5 Summary of Future Ecosystem Responses

The predicted changes in climate in this century are expected to result in significant ecological change, in addition to what has been witnessed to date. Although uncertainties abound, two principles guide the interpretation of these changes. First, ecosystems do not migrate—species do. Second, most species cannot disperse (move) quickly enough to keep pace with the projected changes. These two factors together will affect how future ecosystems take shape as plant and animal species shift their ranges largely independently and at different rates.

Over time, projected changes will result, at least in southern B.C., in trends such as increases in weedy, drought-tolerant, and alkali-tolerant species, and decreases in moisture-loving and acid-tolerant species. Elements of southern forests and grasslands will expand northward but these grasslands will probably be 'mongrel' ecosystems with high proportions of invasive species. Forests will move upslope into alpine habitats. Decreasing snowpacks, shrinking glaciers, melting permafrost, warming streams and oceans, increasing frequency and intensity of disturbances—including pest outbreaks, wildfires, storms, floods, drought and erosion—will negatively affect the structure and function of all present-day ecosystems. In other words, they will undergo ecological upheaval and some will unravel.

As agents of change, shifting disturbance regimes and patterns could become as important as increasing temperatures and changing levels of precipitation. The increasingly acute threat to nature as we know it is not



The ocean is a crucial carbon sink that is now becoming increasingly acidified as it absorbs more and more CO₂. This reduces the availability of calcium, which shellfish such as this dungeness crab need for shell-making.

Photo (left) Jeffrey Walbel, (above) Hanson Quan

climate change acting in isolation, but rather the combination of climate change and intensifying changes made to natural landscapes and systems by humans. Responses of B.C. ecosystems to these changes will be complex and are difficult to predict because they reflect the combined and synergistic effects of changing climate, natural disturbances, land and resource uses, and the spread of invasive species.

Some of these changes may have short-term benefits for people, for example, a longer growing season, but most will adversely affect the province's natural capital and the goods and services that British Columbians derive from nature. Climate-related impacts are already changing the way ecosystems work for us. The ability of ecosystems to produce oxygen, purify water, make soil or adjust to disturbances will be challenged in new and unpredictable ways. As well as natural disturbances, increased human disturbances, diseases, and invasive species will exacerbate the effects of climate change.

What we do on land matters for the oceans as well. Oceans are a large sink for CO₂, but as emissions of CO₂ go up, oceans are absorbing more CO₂, forming more carbonic acid, and acidifying at an escalating rate. Thus as calcium carbonate becomes less available, the oceans are becoming less hospitable for many organisms—including shellfish—that store carbon in their bodies, shells, and skeletons, and on which we directly and indirectly depend for food and our economy.

1.6 Future Species Responses

Species confronting rapid environmental change will either go extinct or survive. The extinction risk increases if suitable habitat conditions either disappear entirely¹⁷⁸ or, as is more likely, if habitats shift more rapidly than resident species can migrate.¹⁷⁹ Species have three survival options: acclimatize to the new conditions, evolve new coping mechanisms, or migrate to suitable habitats elsewhere.¹⁸⁰ For many organisms, evolution probably will not occur rapidly enough to keep up with the current and anticipated rapid pace of climate change,¹⁸¹ especially if habitats have already been degraded by various land uses.

1.6.1 Species of Most Concern

The conservation status of only 3,841 species native to the province has been assessed, a small fraction of the more than 50,000 species that exist here.¹⁸² The relatively well-known species include vascular and non-vascular plants, vertebrates (mammals, birds, amphibians, reptiles and freshwater fish), and selected invertebrates (non-marine molluscs, butterflies/skippers, and dragonflies). For these taxonomic groups, analyses of global and provincial conservation status (imperilled, vulnerable, apparently secure, and so on), trends, and patterns are available.¹⁸³

More usefully, these species have also been assessed for the proportion of their global range that occurs in B.C. Thus we know that about 100 of the 3,841 species assessed have all or the majority (that is, greater than 50 percent) of their global range, area or population within our province.¹⁸⁴ These 100 or so are the species for which British Columbia is known to have the greatest stewardship responsibility.¹⁸⁵ Whether a species is a) endemic and secure, for example, Newcombe's butterweed; b) endemic and at risk, for example, Vancouver Island marmot and several white sturgeon populations; c) widespread but vulnerable for example, bull trout (*Salvelinus confluentus*) or; d) widespread and secure, for example, mountain goat and sooty grouse, for most of these species the most favourable portion of their range, and the area best placed for their conservation, is currently in B.C. In a few instances, the best habitats of highly vulnerable species are on private or First Nations reserve land, or under regional and municipal jurisdiction.

Many of the species officially listed as at risk in B.C. are either northern boreal or arctic-alpine taxa at the southern limit of their range, or they are southern taxa, whose northern range limits extend to southern parts of the province. The northern species are unlikely to persist in outpost localities as climate continues to warm and to push their climatic envelopes northward and upward. If populations of northern species peripheral in B.C. are widespread and secure in the Yukon, Northwest Territories and/or Alaska, B.C. conservation efforts need not be preoccupied with them. In contrast, species with southern affinities that reach their northern range limit in B.C. could spread farther north and become more frequent in a warmer, future B.C.

When one analyses the distributional patterns of species in the province, one quickly notices that both species richness and the numbers of species at risk are highest in southern B.C. The ecological impacts of urbanization and agriculture are also most pronounced in low-elevation areas throughout southern British Columbia. The Coastal Douglas-fir (CDF), Bunchgrass (BG) and Ponderosa Pine (PP) zones, all of which have a restricted distribution in B.C., have already been particularly affected.

Forty-five percent of the CDF has been converted to urban, rural residential and agricultural use. Of particular concern in the CDF is the devastating loss (nearly 90 percent) of Garry oak woodlands, aesthetically pleasing ecosystems with high species richness and many at-risk species.¹⁸⁶ The alteration or conversion of wetlands is also a serious concern. The remaining, mostly secondary forests and woodlands of the CDF are being infiltrated by non-native invasive plants, including spurge-laurel, English ivy, Himalayan blackberry, and numerous grasses, eliminating or reducing native species and changing ecosystem processes.

The BG and PP zones in B.C. are small, but they support much biodiversity, in part due to the juxtaposition of grassland, shrub-steppe, riparian, and forest habitats. The BG zone also represents an insinuation of intermontane steppe of the Columbia Basin into the northern forests. Both southern and northern species frequent the zone. However, nearly 20 percent of the species in the BG and PP zones¹⁸⁷ are at risk because of habitat loss, overgrazing, and the invasion of non-native plants particularly knapweed (*Centaurea* spp.) and cheatgrass (*Bromus tectorum*). Similar to the CDF zone, urbanization has converted 18 percent of the BG zone and 16 percent of the PP zone—including most of the endangered antelope brush/needle-and-thread ecosystem of the southern Okanagan Valley—to urban, rural residential and agricultural use.¹⁸⁸

Another way of addressing this issue is to look at the distributional patterns of species with a majority of their range in B.C., the 'stewardship responsibility group.' The resulting pattern is similar, with increased profile for Haida Gwaii and Vancouver Island and the north, and more focused emphasis on the Lower Mainland and

the Southern Interior. Either way, the four lower elevation biogeoclimatic zones (CDF, BG, PP, and IDF) of southern B.C. host the most species diversity and concentrations of species at risk. These areas also have the highest densities of human population and have lost the most habitat to urbanization, rural residential use, transportation corridors, and agriculture. The same four zones plus parts of the Coastal Western Hemlock zone, particularly Vancouver Island and Haida Gwaii (both heavily logged), are most significant with respect to the stewardship species. Much habitat has been lost or degraded already and the remnants are particularly vulnerable to human impacts in addition to climate change.

1.6.2 Specialised Species

Species of unusual specialised habitats (for example, archaeobacteria and molluscs in hot springs, ferns (for example, *Polystichum kruckebergii*, *P. scopulinum*) restricted to ultrabasic bedrock, and subterranean cave species) are more likely to persist—as long as their special habitats continue to exist. In any case, the special enduring features (hot springs, serpentine talus, and karst terrain) will probably continue to support regionally rare or unusual species and ecosystems indefinitely. The Grand Canyon of the Stikine, the ultrabasic bedrock of the Shulaps Range, hot springs, coastal dunes, karst on Vancouver Island and Haida Gwaii, and spray zones of waterfalls will continue to support some sort of regionally unusual biota almost regardless of how much the climate changes. It probably makes conservation sense to focus on the special enduring features as much as on their unusual contemporary species.

1.6.3 Keystone Species

Some species are more important ecologically than others, regardless of their commonness or rarity. This includes animal species at higher trophic levels—abundant herbivores and top carnivores, responsible for top-down regulation of both terrestrial and aquatic ecosystems. The interplay and feedback among higher trophic levels (consumers: herbivores and predators) can have a large effect on plant species composition and ecosystem productivity.¹⁸⁹ Examples are moose and gray wolf in boreal forest; black-tailed deer (*Odocoileus hemionus columbianus*) and cougar in coastal forests; snowshoe hare (*Lepus americanus*) and Canada lynx (*Lynx canadensis*) in northern forests; overabundant Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) introduced on Haida Gwaii and Rocky Mountain elk (numbers increased as a result of burning practices) in the northern Rockies.

Keystone species are those that exert a disproportionately large influence on ecosystems, much larger than would be expected from their abundance. Some—like beaver—have been characterized as ecosystem engineers,¹⁹⁰ creating habitat or niche space for a host of other species. Keystone species can also include ‘strongly interacting’ species,¹⁹¹ including top predators¹⁹² like gray wolf, cougar, lake trout (*Salvelinus namaycush*),¹⁹³ and falcons, as well as small mammals that form the prey base, such as voles and snowshoe hares.¹⁹⁴

The reintroduction of gray wolves into Yellowstone National Park in Wyoming has demonstrated both the keystone role that top predators can perform and the importance of that role in the face of climate change. Wolves determine the availability of carrion and buffer the effects of climate change for the scavengers reliant on carrion. Without wolves prolonging the late winter carrion, many scavengers would go hungry as the winters warm and shorten.¹⁹⁵

If climate change has a significant impact on any of these sorts of species, most of which are not considered conventionally to be at risk, the cascading consequences for other species and for ecosystems could be huge.^{196,197} The overall effect on biodiversity and ecosystem services will be much greater than that from the extirpation of rare listed species.

1.6.4 Significance of Trees as Foundation Species

Trees also provide a hugely important role and have been described as ‘foundation’ species.¹⁹⁸ Impacts on B.C.’s common and abundant tree species, which so dominate the province’s forests, will also have consequences for virtually every forest organism—from caribou to birds and beetles to boletes.

Lodgepole and other pine species will probably continue to be attacked by bark beetles as well as by insects and diseases of young stands. The extent and severity of outbreaks of bark beetles and other pathogens on pine species have long-term effects; for example, attacks by bark beetles lead to declining mature overstory trees of ponderosa pine forests, in turn impacting wildlife species reliant on these trees for habitat.¹⁹⁹ White spruce is vulnerable to a combination of spruce beetle and root rot and perhaps spruce budworm. Lodgepole pine and white spruce should persist in B.C. but likely will become less abundant in this century (see Fig. 7 below for white spruce). Subalpine fir (*Abies lasiocarpa*) could decrease at lower elevations generally and at high elevations in southern B.C., but increase in abundance at higher elevations in the north.

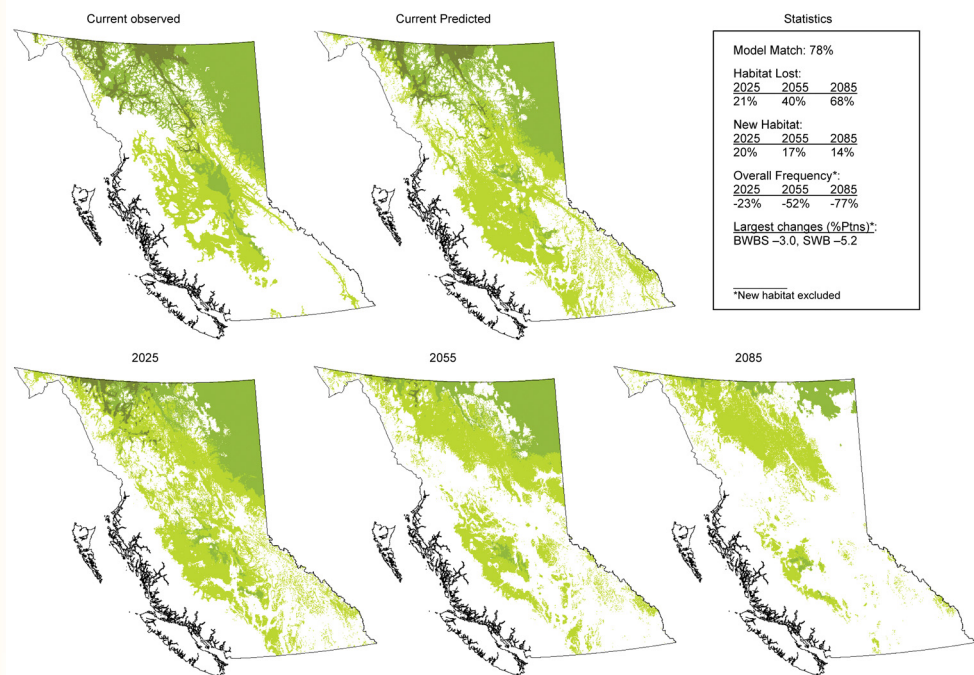


Figure 7: Observed and predicted range and frequency for *Picea glauca*. (Light green indicates < 5% cover, Olive green > 10% cover, Middle green between 5 and 10%).²⁰⁰

Deciduous trees—for example trembling aspen, paper birch, and cottonwood (*Populus balsamifera*)—are also having their own problems with defoliating insects and disease.^{201,202} After insect epidemics and/or fire, their ranges might shift into areas originally occupied by evergreens, in large part because of a pioneering/early successional lifestyle and the ability to reproduce vegetatively.

The climate in central and parts of northern B.C. could become suitable for Douglas-fir (*Pseudotsuga menziesii*) (Fig. 8, on next page) and maybe even western hemlock (*Tsuga heterophylla*) within 80 years.²⁰³ Western redcedar (*Thuja plicata*), B.C.’s provincial tree, could expand its range significantly in the Kootenays, the central interior, and on the north coast, but could also suffer widespread decline in south coastal B.C. generally.²⁰⁴

B.C. is a forested province. Individual tree species are of paramount importance to B.C.’s biodiversity and ecosystem services. Trees are integral to carbon sequestration and storage, and albedo characteristics (discussed in part 2 of this report). There are relatively few dominant tree species and not much redundancy in that ecological niche. Genetically, many of the province’s tree species may be severely impacted by the climate change challenge (see fuller discussion on genetics in the section on Adaptive Capacity of Trees). For

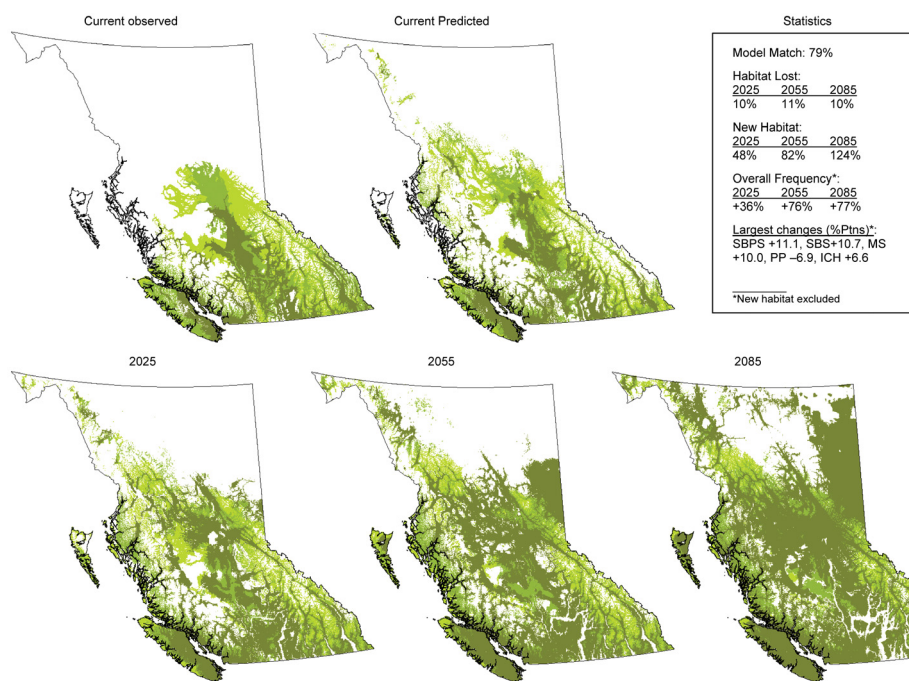


Figure 8: Observed and predicted range and frequency for *Pseudotsuga menziesii*. (Light green indicates < 5% cover, Olive green > 10% cover, Middle green between 5 and 10%).²⁰⁵

all of these reasons, B.C.'s tree species should be of high conservation concern. Some, like whitebark pine and limber pine (*Pinus flexilis*), could be legitimately considered to be at risk. Others, like western redcedar and yellow-cedar, deserve close attention, especially in light of their cultural and economic significance, and the chronic highgrading of these species on the coast.

1.6.5 Importance of Step-wise Jumps and Long Distance Dispersal for Tree Species

Past range shifts during the postglacial period of the Holocene, inferred from paleoecological studies²⁰⁶, support the importance of small outlying populations during migration. Initial calculations of migration rates based on the pollen record for north temperate trees indicated very rapid postglacial migration during the Holocene.²⁰⁷ More recent evidence suggests that these rates were overestimates. Small northern disjunct populations, which typically are ignored in regional paleoecological studies, appear to have provided crucial foci for colonization and to have spread northward during the Holocene.²⁰⁸ These populations are liberated from what are called 'migrational loads' because of barriers to gene flow, and may be adapted to extreme conditions, making them valuable genetic sources.²⁰⁹ Habitat loss and fragmentation will hinder the migration of many species, but some opportunistic species could use such outpost populations for sallies through a patchy, disturbed environment that allows faster migration than forecast for a continuous environment.²¹⁰ In general, we don't know nearly enough about different rates of dispersal and migration. Better projections of future ecosystems depend on a much better understanding of and accounting for dispersal and migration.²¹¹

1.6.6 Summary of Future Species Responses

Species confronting rapid environmental change will either go extinct or survive in one of three ways: by acclimatizing, evolving, or migrating to suitable habitats elsewhere. Those that adapt in their original location will have additional competition from other species or genotypes better suited to the new local environment. Many species will not be able to keep up with the rapid pace of climate change, especially if habitats have already been degraded by various land uses. Both species richness and the numbers of species at risk are

highest in low elevation areas of southern B.C., where the current conservation crisis will only get worse as land and water degradation exacerbates climate change impacts.

Species adapted to specialised habitats are more likely to persist as long as their special habitats continue to exist. Impacts from climate change to keystone species, which exert a disproportionately large influence on ecosystems, will have huge cascading consequences for other species and for ecosystems. Indeed, the overall effect on biodiversity and ecosystem services will be much greater than extirpation of some threatened and endangered species.

While climate change will force widespread species migrations poleward, to higher elevations, or to cooler aspects, many species, like trees, cannot migrate quickly enough. Tree species, which dominate the province's forests, can be considered foundation species of paramount importance to B.C.'s biodiversity. Some, like whitebark pine, are already of conservation concern, and others deserve close attention. In addition, historic patterns of dispersal of these species are being disrupted by habitat loss and fragmentation, so there is uncertainty about how such populations will migrate and disperse in response to rapid climate change.

1.7 Future Genetic Responses

Genes are the functional units of heredity and evolution. The genetic diversity that exists within species enables them to adapt to changing environments and is the ultimate source of biodiversity at species and ecosystem levels. Understanding species and ecosystems, their biology and ecology, requires at least a rudimentary understanding of genetics and systems of genetic variability.²¹² A key to conserving genetic resources is understanding how species adapt to heterogeneous environments, which B.C. has in abundance. This is particularly true when the heterogeneous environments are changing, in our case as a result of urbanization, landscape industrialization, natural resource management, and climate change. But we have been challenged by a lack of understanding of genetic variation for all but economically important or scientifically significant species, for example, commercial tree species and salmon. Fortunately, the well-studied commercial tree species (e.g., *Pinus* spp., *Picea* spp., *Pseudotsuga menziesii*) are also important foundational species for vast areas of forest and our genetic understanding of other native trees is growing.

1.7.1 Clinal and Racial Variation

Patterns of genetic variation in species can be characterised as clinal and racial. Clinal variation is continuous variation in a character along some environmental gradient within a species' range. For example, some species of *Pinus* exhibit continuous variation in needle length, chlorophyll content, cold hardiness, and rapidity of shoot development in the spring, along altitudinal and latitudinal temperature gradients. Most species (plants in particular) with a continuous range that includes more than one altitudinal or latitudinal climatic zone probably have clinal variation in physiological traits adapting them to the environmental conditions prevailing in the different parts of their range.²¹³

Racial variation is discontinuous, representing genetically distinct populations within a species. Ecotypes are a kind of racial variation and species can adapt to heterogeneous environments via different ecotypes, which can be geographic, elevational, climatic, or edaphic. Racial differences within a species can be greater than the differences between species in the same genus. Most wide-ranging forest tree species have such racial variation.^{214,215}

The genetic variation responsible for differences in these traits cannot be assessed or inferred from phenotype alone. The genotype must be studied, so as to sketch the genetic architecture of species and determine how the total variation is distributed among the different levels of organization: species, variety, race, provenance, family, and individual. Tracing this genetic architecture has been done (via tree breeding research) for most major commercial tree species, some commercial fish such as salmon, some mammals such as bears, major

agricultural crop species, and a few other well-studied species (for example, fruit flies). The genetic details of most other species are unknown. Because tree species are so well studied and will have such a profound impact on B.C.'s ability to sequester carbon, the research into genetic variation in trees provides some indications of impacts to genetic resources from climate change.

1.7.2 The Ecological Theatre and the Evolutionary Play: B.C. Tree Species on Stage

The key differences within tree species tend to be physiological or phenological, not morphological. Such functional characteristics relate to survival, growth, and reproduction. For example, when considering the genetic variation of boreal forest trees, adaptations can be viewed very simply as representing a trade-off between selection for high growth potential in a short but intense growing season and selection for hardiness (high cold tolerance) in a severe climate. One can examine the trees of the boreal forest in terms of this balancing act. Perhaps there is a prototypical boreal tree species, for example, white spruce, which has life history traits including regeneration on a variety of seedbeds, shade tolerance, slow steady growth, extreme cold tolerance, and abundant small, light seeds that disperse widely. But most other boreal tree species do

not seem to resemble this prototype. All species are different—they were molded evolutionarily in different environments, they have different systems and patterns of genetic variability, they achieve adaptation in different ways, and they ‘perceive’ their environment differently, which is why they respond ‘individualistically’ to climate change.²¹⁶

One can conclude that each of B.C.'s tree species will respond differently to climate change, and that the wide-ranging species will probably respond in different ways in different parts of the province. It is likely that species will adopt various adaptive strategies that stretch along a continuum ranging from:

- *the specialised*, with lots of genetic differentiation, like Douglas-fir. Specialists have physiological processes attuned to a small range of environments; phenotype controlled by genotype; environmental variability and change accommodated by genetic variation, to:
- *the generalised*, with lots of phenotypic plasticity, like western white pine (*Pinus monticola*) or Pacific dogwood (*Cornus nuttallii*). Plasticity enables individuals to alter their morphology, physiology, or development in response to environmental variation and change. Generalists have physiological processes attuned to a broad range of environments; phenotype controlled by environment; and environmental variation and change accommodated by phenotypic variation.

In the middle of this continuum are whitebark pine and Garry oak (*Quercus garryana*), which are plastic and exhibit lots of genetic differentiation. Most B.C. conifers are genetically specialized.



Ponderosa pine, a genetically specialized species that could be vulnerable to rapid climate change.

Photo Geoffrey Holman

1.7.3 Genetic Drift and Natural Selection in Trees

Random genetic drift refers to change in gene frequencies due to chance alone, change that results from random breeding within very small populations. Genetic drift has not played a large role in the genetics of most of B.C.'s native trees, due to high levels of gene flow via wind-dispersed pollen. However, genetic drift could contribute to evolutionary processes in some geographically isolated forest stands. Where could it happen? Perhaps, genetic drift might occur in skips—the small islands of trees that survive major wildfires or insect epidemics or even urbanization. Chance selection of alleles from the few surviving seed trees in a skip could lead to significant shifts in gene frequency in the offspring that reoccupy the disturbed area. Presumably, in the wildfire scenario, genetic drift could happen in white spruce, subalpine fir, tamarack (*Larix laricina*) and Douglas-fir, though not in the fire-adapted lodgepole pine.

Trembling aspen, the most widespread tree in North America, provides a very different scenario. It has a largely clonal mode of reproduction. Sexual events are very infrequent. Perhaps aspen will respond to climate change, especially to extreme events, with periodic intense bursts of sexual reproduction, as happened after the big Yellowstone wildfires of 1988.²¹⁷ This can result in a mosaic of genetically different clones across the landscape, that is, genetic diversity at a landscape rather than a stand level. However, aspen could be at as much risk from climate change as conifers because it is host to a much wider range of insects and diseases than conifers.²¹⁸

Directional selection is probably happening to lodgepole pine under the onslaught of the mountain pine beetle. There is evidence that beetle resistance varies among races of lodgepole pine.²¹⁹ Beetle-resistant genotypes will experience strong positive selection during a beetle epidemic.

As a generalisation, we can anticipate that genetically specialised species will respond to climate change by differential survival of the races or genotypes best suited to future conditions. This is the essence of adaptation and evolution, but climate change could be happening too fast to ensure healthy populations of species—like trees—with long generation times. Although most tree populations have enough genetic variation to recover in the long term, in the short term there will be forest declines. Species adapt to environmental changes through natural selection at a rate negatively related to their generation time (that is, reproductive age) and positively related to their within-population genetic diversity.

1.7.4 Adaptive Capacity of Trees

Conifer forest stands, whether naturally regenerated or planted, typically have high levels of genetic diversity.^{220, 221} There is, however, uncertainty about how resilient forest trees will be and how much genetic variation will be lost. Because of long-distance gene flow via pollen, widespread conifers and wind-pollinated broadleaves may not lose much genetic diversity, but those that have smaller ranges, occur at low population densities, or are suffering from population crashes due to insect or disease epidemics may.²²² This suggests a large capacity for adaptation, but in the interim, populations could go through demographic reductions that lead to genetically impoverished forests.

Some population geneticists contend that climate warming could ultimately exceed the adaptive capacity of conifers because a) if populations (interbreeding individuals) are locally adapted, as they are in most of our conifers, climate change will cause conditions to deteriorate throughout a species' range, not just at the margins of the range,²²³ and will push many populations beyond their physiological limits of temperature or moisture tolerances; b) mortality induced by extreme climatic or disturbance events will result in losses of genetic diversity; and c) the expected rate of change will be too fast for an adaptive tracking response by tree species with long generation times and life-spans.²²⁴ These factors could lead to significant genetic erosion and forest decline for several forest generations.^{225, 226}

Research suggests that temperature increases over 3 degrees Celsius would result in drastic declines and

extirpation of local populations in the southern range of lodgepole pine.²²⁷ Thus long-lived specialists may have to migrate (or have facilitated migration) to survive, to where suitable environments exist. Many plant species, including trees, have survived past climate changes by migrating to suitable habitats elsewhere. This time, however, climate is expected to change, and suitable habitats to shift, at rates that will exceed the migration rates of many plant populations.^{228, 229, 230} This begs the question of the role of facilitated migration, as has been explored on an experimental basis by planting of whitebark pine north of its range, to help nucleate the northward migration of the species.²³¹

Losses in productivity and increases in pest populations could be anticipated for several generations while species migrate and genotypes are rearranged by natural selection.²³² During this ‘lag’ period, ecological opportunism will be an advantage.²³³ Invasive, annual, herbaceous species with long-distance seed dispersal, and pioneer tree species, will probably have the best chance of migrating and adapting in the short term to a changing climate.²³⁴

Climax species that are not good colonizers, species with short-distance seed dispersal (for example, among B.C. trees, ponderosa pine, Douglas-fir, western white pine, and *Abies* spp.), and small local populations (*Larix lyallii*, *Chamaecyparis nootkatensis*, and *Pinus flexilis*) will probably be least successful at migration in the short term. Ironically it is the interior zones dominated by Douglas-fir and ponderosa pine that are predicted to substantially increase in areal extent, yet the tree species are predicted to be relatively poor migrants. This incongruence should be highlighted as a limitation to predicting ecosystem reorganizations with climate change. These specialized species, however, do have high adaptive capacity in the long term to respond evolutionarily to new environments.

In contrast, generalists with lots of phenotypic plasticity will respond to climate change by ‘attempting’ to ride it out within the bounds of their plasticity. Individuals of highly plastic species can tolerate a wide range of environments and may be less sensitive to climate change. For example, there are 1000-plus year-old Sitka alder glades in B.C., while a sedge in the European Alps can be more than 2000 years old.²³⁵ Such clones presumably have persisted through a series of climatic variations (such as the Medieval Optimum and the Little Ice Age) without shifting to lower or higher elevations. However, they might have less adaptive capacity in the long term for the drastic changes anticipated.

Eventually—when individuals of a plastic species can no longer tolerate the changes—they too will have to evolve or migrate²³⁶ but they may not have to move as far to survive. Or if an ecosystem has a high degree of inertia and its responses lag behind changes in climate, then at least some of the component species (like forest understory plants) could be buffered in the near term from climate change.²³⁷ On the other hand, if generalist species are handicapped by low levels of genetic diversity, as is often the case, including western white pine and yellow-cedar and Garry oak,²³⁸ they could be more susceptible to exotic pathogens (like white pine blister rust) or other manifestations of climate change, such as freezing damage.

Western redcedar, B.C.’s provincial tree, is an enigma. It is a relative newcomer to the province, is very long-lived and has rather sporadic low seedling survival and slow establishment. Yet it was able to infiltrate coastal and wet interior forests, and spread to its current range within a few thousand years.²³⁹ It also appears to be well-defended against insect pests and fungal pathogens. However, redcedar has very low levels of genetic diversity and is highly inbred²⁴⁰—not a recipe for its long-term success. A possible explanation is that it has arbuscular mycorrhizae, which provide networks with a wide array of understory plants that might facilitate regeneration.²⁴¹

British Columbia’s tree species are under threat. Of course these species have survived environmental change over millennia but the scale of change anticipated will challenge all of the province’s native trees, regardless of their adaptive strategies.

1.7.5 Genetic Responses in Other Species

In addition to trees, other forest organisms are vulnerable, for example understory plants. Although long-lived trees may buffer understory plants initially, once these foundational species die, the shifts in understory composition will be rapid because of the changing climatic conditions. Levels of genetic variation in herbaceous plants are usually low, at least within populations. They can, however, have lots of ecotypic variation.²⁴² Many species exhibit local adaptation (for example, racial or ecotypic) to climatic conditions within their natural ranges.²⁴³ Is this true for the guild of understory herbs? What about shrubs? Currently, there aren't enough data on shrubs to answer such questions. It is also unlikely whether answers would be amenable to generalisation. For example, in forest shrubs we would expect different patterns of genetic variation among major groups, including the *Ericaceae* (a family that dominates the shrub layer of many B.C. forests), willows, the *Caprifoliaceae*, and the *Rosaceae*, if only because they have different breeding systems and life history strategies. In tundra environments, dwarf birch (*Betula nana*) because of its ability to spread horizontally below ground (and avoid frost thaw problems) is already expanding northwards.²⁴⁴

Also, the process of evolution cannot be discounted. While generally thought of as a slow, gradual process, it can occur rapidly, even in macro-organisms, and especially under strong directional selection, for example, due to fishing and hunting by humans.^{245, 246} Paleocological studies indicate that adaptive divergence can evolve on a time scale comparable to change in climate, within decades for herbaceous plants, and within centuries or millennia for longer-lived trees, which implies that biologically significant evolutionary responses could accompany the climate change underway now.²⁴⁷ Rapid genetic adaptation to recent climate change has already been documented for a few wild species.^{248, 249}

Wild Salmon

Pacific salmon provide an excellent example of another scenario for genetically diverse specialists. Salmon have evolved a diversity of genotypes, populations, behaviours and environmental sensitivities in response to considerable environmental variability and uncertainty. The salmonid evolutionary strategy of locally adapted populations works well when linked to a dynamic and variable (within limits) marine environment and to the availability of healthy, complex, and connected freshwater and terrestrial habitats.²⁵⁰

In Bristol Bay, Alaska, record catches of sockeye salmon have occurred from the late 1970s until recently. The Bristol Bay 'stock complex' consists of several hundred discrete spawning populations. Individual populations display diverse life history characteristics and local adaptations to the variation in spawning and rearing habitats in the area's lake and stream systems. This 'biocomplexity' has enabled the aggregate of populations to sustain its productivity despite major climate change affecting the freshwater and marine environments during the previous century. Different populations that were minor producers during one climatic regime have dominated during others, thus maintaining the resilience of the stock complex to environmental change. Population-specific variability in response to climate fluctuations is ultimately responsible for the resilience of the entire stock.

“...the resilience of Bristol Bay sockeye is due in large part to the maintenance of the diverse life history strategies and geographic locations that comprise the stock. ... If managers in earlier times had decided to focus management on the most productive runs and had neglected the less productive runs, the biocomplexity that later proved important could have been lost.”²⁵¹

1.7.6 Isolated Populations

Populations isolated geographically or environmentally from the main range of their species can evolve genetically distinct races or subspecies. In B.C., such differentiation is a fairly frequent theme of island and disjunct populations.²⁵² The Kermode bear is a good example of how small population size, geographic isolation on coastal islands with water-barriers to dispersal, and random genetic drift can act in combination to maintain a high frequency of the genotype responsible for the white coat trait of kermodism. Climate change could increase such between-population genetic diversity, insofar as insularity increases (for example, in the alpine zone²⁵³ as treeline moves upward, or on the coast as sea level rises), as disjunctions increase (for example, by long-distance dispersal), or as currently continuous, widespread species distributions become fragmented.

Many of the species officially deemed ‘at risk’ in B.C. occur peripherally in the province, as is clear from their distributions. Many of them have been listed, by the Conservation Data Centre, largely because their geographic ranges transcend political boundaries and marginally enter this province, where they are rare. However, some peripheral populations are more significant than others with regards to impacts of climate change. There is a difference between continuous peripherals and disjunct peripherals.²⁵⁴ Disjunct peripheral populations of long standing can make important contributions to diversifying genetic material in several ways:

- The more disjunct the populations are, the more divergent they are likely to be due to random founder effects, and the more likely they are to further diverge genetically.²⁵⁵



The burrowing owl is already under stress in B.C. along the northern periphery of its traditional range.

Photo Frank Leung

- Geographically isolated populations generally are more genetically depauperate, which may handicap their survival, but also more genetically distinct, which could provide a greater evolutionary legacy to the species.
- Species with life-history attributes that reduce gene flow are more likely to form evolutionary significant peripheral populations, by imposing a form of isolation. As in self-fertilizing or allopolyploid apomictic plants. Pond-breeding amphibians in dry climates, for example, show greater between-population differences than does the stream-breeding tailed frog.²⁵⁶
- Once isolated, species with short generation times will in principle diverge more quickly than species with longer generation times.
- Genetic divergence can also occur when peripheral populations occupy habitats that are very different from, or more stressful than, habitats in the more continuous range of a species, and thus experience strong selection pressure.²⁵⁷ Selection could be stronger in disjunct populations or it could just be different—acting on different traits or selecting traits differently.²⁵⁸
- Disjunct peripheral populations are more likely to be adapted to extreme environmental conditions than continuous peripheral populations due to isolation from gene flow, and therefore should be a conservation priority.

Northward migrations during the Holocene evidently had significant genetic consequences, such as reduced genetic variability in northern populations that passed through ‘serial bottlenecks’ and increased genetic variability in regions where populations from separate isolated refugia subsequently became mixed.²⁵⁹ Similar genetic consequences are likely in future northward migrations.

1.7.7 Cryptic Species

Many species possess ‘hidden’ intra-specific variation, that is, traits not obviously expressed in their phenotype, leading in some cases to what are referred to as ‘cryptic species’. If the genetic variation revealed by DNA analysis and other evidence is significant and has a distributional pattern, two or more reproductively isolated but morphologically indistinguishable species can be designated in what previously had been considered a single species. For example, the seaside juniper (*Juniperus maritima*) of the Strait of Georgia–Puget Sound area is now recognised as distinct from the more widespread Rocky Mountain juniper (*J. scopulorum*).²⁶⁰ In woodland caribou, the mountain caribou ecotype of southeastern B.C. has a different foraging strategy than other woodland caribou, which may eventually lead to speciation. The winter wren (*Troglodytes troglodytes*) also has ‘hidden’ diversity, and could be divided into two species—without genetic analysis they are very hard to tell apart except by their songs—with a contact zone in northeastern B.C.²⁶¹

The plant genus *Draba* has many species in B.C., especially at high elevations, and an inordinate number of at-risk species in northwestern North America generally. Recent studies have revealed numerous cryptic biological species within some supposedly well-known, circumpolar, taxonomic species of *Draba*.²⁶² *Oxyria digyna* (mountain sorrel) is another circumpolar, arctic-alpine species common in the mountains of B.C. Though morphologically uniform, it has lots of genetic diversity that can be revealed by DNA analysis. The alpine biogeoclimatic zones of north central B.C. turn out to be a hotspot of *Oxyria* genetic diversity, an unexpected finding if the region was entirely covered by ice in the late Pleistocene, as is generally believed. The results have been interpreted as evidence for a refugium well within the accepted limits of the Cordilleran ice sheet.²⁶³

If such genetic and molecular diversity exists in *Draba* and *Oxyria*, then other widespread arctic-alpine species could well exhibit similar patterns. And a refugium in the mountains of northern B.C. would suggest a much more complex biogeographical history for the region, with major implications for the origin and migration of many northern species. This suggests that there will be more impacts to genetic diversity due to climate change than was previously thought before cryptic species and hidden variation came to light. Soil microbes have even more cryptic intraspecific variation than plants, opening up another whole area of enquiry. Also, impacts to

B.C.'s alpine ecosystems, traditionally considered biodiversity 'coldspots' and projected to shrink dramatically in this century, could be much more biologically significant than many realize.

1.7.8 Hybridisation

Hybridisation is an important evolutionary process, especially in plants but also known to occur in many vertebrates, including birds, freshwater fish, amphibians, and ungulates. Hybrid zones already exist in B.C. For example, much of central B.C. is a big zone of hybridisation between white and Engelmann spruce. B.C. also is part of a huge hybrid zone between red-shafted and yellow-shafted subspecies of the northern flicker.²⁶⁴ Hybridisation can result in the blending or homogenisation of genetically distinct lineages. It can also result in hybrid swarms with much genetic variation or (especially if accompanied by polyploidy) in new species—as it frequently has in plants.²⁶⁵ Hybridisation probably will increase as climate changes, as species and populations migrate and come into contact with related species or populations from which they were previously isolated, and as habitats themselves become mixed up, recombined, and effectively hybridised.²⁶⁶ A big danger is the introduction of alien congenics that can potentially swamp native species.

1.7.9 Summary of Future Genetic Responses

The ability of species to respond genetically to environmental change is difficult to predict. It depends on their population genetics and life history traits. However, other than a handful of commercially important species, such as the conifers, we know very little about the genetic architecture of B.C.'s native species.

With respect to tree species, the factors of rapid climate change and increased disturbances will ultimately lead to genetic erosion (reduced genetic diversity) and declining productivity of populations for several forest generations at least. This decline probably will be greatest for genetically specialized species, for example, Douglas-fir and ponderosa pine. During this period, opportunistic pioneer species that can adjust phenotypically (by altering their morphology, physiology, or development) to different environments (thereby exhibiting 'plasticity') will have the best chance of migrating and adapting. Migrations will have variable consequences for different species.

There are likely to be different patterns of genetic variation among the major groups of plant species. Some shorter-lived herbaceous species, unlike trees, might be able to evolve on a time scale comparable to change in climate, that is, within decades. Invasive short-lived herbs with long-distance seed dispersal, for example, knapweed, will probably be most successful at migrating in a changing climate, but B.C.'s specialized native species could have the best genetic potential to adapt over time.

Some species have evolved rich genetic resources to deal with considerable environmental variability. For example, sockeye salmon have developed much local, stock-level genetic variation in response to heterogeneous spawning and rearing habitats. This genetic diversity has enabled sockeye to adapt locally and quickly, and to sustain productivity despite past fluctuations in climate. This should help them respond—within limits—to future climate change.

British Columbia species that live at the edge of their range as peripheral populations (for example, burrowing owl), and species that harbour genetically distinct and reproductively isolated populations as cryptic species (for example, seaside juniper), will be important genetic resources in the future. Peripheral populations can possess valuable adaptations to local marginal environments that could become more widespread within the species. They also can have the genetic raw material for evolution in changing or new environments; populations close to northern and southern range boundaries are likely to be better adapted to some environmental changes than the modal (most frequent) genotype. But even if a species' potential range expands, much of its newly available habitat may have already been converted or degraded and will most likely be increasingly vulnerable to invasive species.

Hybridisation, a common process in many species and in B.C., will probably increase as species and populations migrate and mix with differing genetic consequences. Alien species—perhaps including genetically modified organisms—could genetically swamp related native species.

1.8 Resilience and Ecological Adaptation

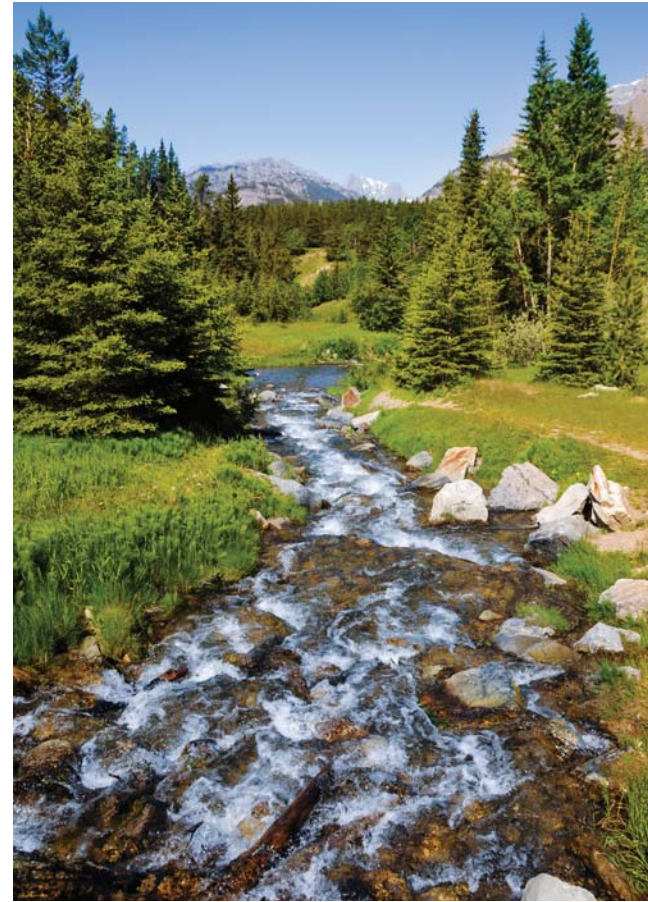
Landscapes with intact, functional natural ecosystems probably will be better equipped to accommodate, adapt to and recover from the impacts of climate change than industrialised landscapes with ecosystems fragmented and degraded by human activities, especially if they are large landscapes.²⁶⁷

1.8.1 Moderated Microclimates

Natural ecosystems, especially forests but also shrublands, grasslands and tundra, create their own microclimates,²⁶⁸ and these microclimates shelter and buffer the organisms of the ecosystems from many of the vicissitudes and extremes of the broader regional climate. This sheltering effect could lessen the rate and amplitude of change experienced by the resident species, and give them more time to adapt and migrate.²⁶⁹

Ecosystems provide thermal and hydrological buffering. For example, forests absorb heat in the summer and radiate heat in the winter, thus maintaining more stable temperatures within the forest throughout the year, and reducing temperature stress and frost damage in both spring and fall.^{270, 271} There are good reasons why many vertebrates use forests for thermal cover.

Forests also play a major role in the water cycle, as a result of canopy interception of precipitation, redistribution by tree crowns, evapotranspiration, and influences on snowmelt, infiltration rates, overland flow, erosion, and streamflow.²⁷² With respect to climate change, the most beneficial service of intact forests—and intact ecosystems in general—could be hydrological buffering, their contribution to maintaining hydrologic connectivity²⁷³ and water quality and quantity in environments increasingly subject to extreme events (storms, floods, erosion and droughts) as well as to changes in streamflows and water temperatures. In a Montana scenario of doubled CO₂, air temperature increase of 4°C and 10 percent more precipitation, snowpack was projected to melt 19 to 69 days earlier in the spring (depending on topographic location) and average summer streamflows to decrease by as much as 30 percent from current discharge levels.²⁷⁴ Natural ecosystems will have plenty to deal with even without the added burden of land use change.



Natural forests buffer the environment from extreme weather events such as storms, floods, erosion and droughts. Photo Yanik Chauvin

1.8.2 More Biodiversity?

If landscapes lose natural biodiversity, they are apt to become less productive, less stable, less resistant to environmental perturbations, and thus less resilient—that is, less likely to return to their previous condition and function following disturbance.^{275, 276, 277} However, the relationships between diversity and productivity, stability, and resilience have been debated for decades, and the relationship investigated has often been that between **species** richness, not biological diversity, and ecosystem function. These relationships are complex

and have not lent themselves to unequivocal results and robust generalisations. For example, it has not been firmly established that mature or old-growth forests, or intact forest landscapes dominated by old or wild forests, have more biodiversity than all second-growth forests, or some kinds of managed forest landscapes. It depends on the type of forest and its disturbance regime, on scale (stand versus. landscape), on the taxonomic groups sampled, and on the biodiversity elements considered (genes, species, ecosystems, interactions—rarely are all included).

A key biodiversity point is that each ecosystem has its own unique history and that is part of its biodiversity. The longer a particular group of species interacts in a place the more distinctive the biodiversity becomes, because it develops its own trajectory. These trajectories are part of biodiversity; the loss of those unique trajectories through repeated non-natural disturbance is a loss of biodiversity.

Three generalisations with regard to forest biodiversity seem reasonable:

- 1) Forests of all age classes, including very young and very old, are important for maintaining the diversity of all groups of organisms, from microbes to mammals.
- 2) Some groups of organisms, like canopy insects, epiphytic lichens and epixylic bryophytes, and aquatic invertebrates, are more sensitive to forestry impacts than are other, less specialised, more mobile groups like (most B.C.) vertebrates.
- 3) Natural or wild forests have more taxonomic, structural, age-class, and functional diversity than do industrially managed forests.

Conventional production forestry impacts the biota in many ways, including:²⁷⁸

- Simplifying forest structure;
- Altering microclimate;
- Interrupting ecological continuity at relatively frequent intervals;
- Truncating natural succession at both ends of the trajectory; forcing it into a 50- to 100-year-long stand replacing cycle;
- Increasing fragmentation; reducing the extent of, and connectivity²⁷⁹ among, patches of mature and old forest;
- Directly or indirectly affecting aquatic organisms through hydrologic impacts.

Ecological resilience is defined as “the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes” or to “absorb disturbance, undergo change and still retain essentially the same function, structure, identity and feedbacks.”²⁸⁰ Although some ecosystems may retain key processes and functions, it is highly unlikely that contemporary ecosystems will retain the same structure/species composition as climate changes.

Arguing from ecological principles, we can expect that ecosystems with a greater variety of species and interactions are more likely to persist over time because not all species are affected by disturbances in the same way.^{281, 282} The more species an ecosystem has, the more limited will be the impact of a given disturbance on the ecosystem as a whole.^{283, 284} This is particularly significant in a northern region like British Columbia, where most of the ecosystems are dominated by relatively few species, or regulated by a handful of top predators.

Ecosystems with full suites and robust populations of predators, keystone species and foundation species are more robust themselves. Wild or natural ecosystems, whether forests, grasslands or wetlands, typically have



Conservation of biodiversity is everyone's responsibility.

Photo Ken Canning

more dominant and highly interactive species than their managed, simplified or degraded analogues. Intact natural ecosystems are more resilient than degraded ecosystems, to disturbance and change.^{285, 286, 287}

If intact ecosystems have resident species with a higher proportion of mature individuals and with more genetic diversity than secondary or degraded ecosystems, as some claim,^{288, 289} then one could conclude that both the genetically diverse species and the intact ecosystems they inhabit have greater resilience.²⁹⁰ For example, European birch (*Betula lenta*) evidently has 'warm year' and 'cool year' genotypes that enhance seedling survival in variable environments.²⁹¹ 'Warm year' genotypes should increase in frequency *in situ* in a warming climate with a much faster response than northward migration of southern genotypes.²⁹² Moreover the northern populations should be better adapted to their local conditions than the southern populations, at least initially.²⁹³

With respect to forestry, natural or wild forests are more resilient to environmental change and disturbances than are industrially managed forests because they have greater biodiversity—in all its elements; genes, species, ecosystems, structure, function and interactions. Resilience of forests includes the ability to regenerate after fire or windthrow, to resist and recover from pests and diseases, and to adapt to changes in temperature and water availability—including those resulting from climate change.²⁹⁴

Natural, unfragmented forested landscapes should also be more resilient than fragmented industrialised landscapes. This should not be interpreted as arguing in favour of homogeneous, high-connectivity landscapes dominated by old forests, everywhere. Where very active natural disturbance regimes result in heterogeneous landscapes with a mosaic of age classes, as in many of B.C.'s interior forests, increased landscape homogeneity and forest connectivity (resulting from fire suppression) increase the likelihood of landscape-scale outbreaks of insects and diseases, and reduce landscape-level resilience.

1.8.3 Species Adaptation, Migration and Survival

As climate changes and climate envelopes shift, many species will respond by migrating northward or upward, or are already doing so. This kind of migration (that is, long-term range shifts, not diurnal or seasonal movements) typically is a slow process. Species will be able to migrate most easily through intact ecosystem types that they already inhabit, and through similar adjacent unfragmented ecosystems. The ability of species to reach new climatically suitable areas will be hampered by habitat loss and degradation, and their ability to persist in new habitats is likely to be affected by exotic invasive species.²⁹⁵ For example,



Existing parks on their own cannot safeguard biodiversity. Additional buffer areas, such as the Taku valley where these mountain goats live, are needed.

Photo (top) Timothy Epp, (above) Laure Neish, (right) Johnny Mikes



grassland species such as bitterroot (*Lewisia rediviva*), arrowleaf balsamroot (*Balsamorhiza sagitta*) and yellow badger (*Taxidea taxus*) should be able to spread relatively easily through existing intact grasslands, adjacent savanna, and perhaps also dry open forests of ponderosa pine and Douglas-fir. But their migration through fragmented, disturbed, or derelict patches of such ecosystems could be constrained by roads and other linear infrastructure, by agricultural and urban areas, by habitats rendered hostile by inappropriate or unregulated motorized access, overgrazing, invasive species, or (in the absence of ground fire)²⁹⁶ dense conifer regeneration.

For another example, some species of interior Douglas-fir forests with their northern limits in sub-boreal forests are projected to increase in abundance within the core of their current range, while gaining new habitat upwards in mountainous terrain and northwards in the sub-boreal and boreal forests of central and northern B.C.²⁹⁷ Such movements will happen faster (less slowly) and more effectively in and through large expanses of intact contiguous forests—or at least broad corridors with high connectivity—than in and through fragmented landscapes.²⁹⁸ Unfortunately for this scenario, the central part of the province is now a vast fragmented checkerboard criss-crossed by a network of industrial roads, due to decades of clearcut logging and the more recent salvage logging of forests attacked by the mountain pine beetle.

Intact natural landscapes constitute the best options for wildlife survival during climate change because they provide functional matrices or corridors for migration and moderated microclimates for short-term persistence and longer-term adaptation.^{299, 300, 301} In conjunction with climate modelling, planning for future migrations must attempt to maintain connected landscapes managed specifically for climate change.^{302, 303} The concept of corridors and linkages also applies to the land-sea interface.³⁰⁴

Non-degraded, supportive habitat provides the best chance for the movement and transport of materials, nutrients, energy, and organisms,³⁰⁵ so planning should strive for:

- 1) *very large core intact area* complexes;
- 2) *large intact mountain ranges*; to maintain their key ladder role across ecosystems and life zones;
- 3) *spacious migration corridors/landscape linkages*—south-north, west-east (transmontane), upslope; and
- 4) *supportive buffer areas*.

Intact ecosystems facilitate migration by providing wildlife with the kind of contiguous movement corridors that are lacking or interrupted in fragmented ecosystems. Fragmentation leads to more stress on animals with higher energy and mortality costs due to increased rates of predation, hunting, and vehicle collisions.³⁰⁶ Modern forest management has attempted to approximate patterns of natural disturbances by leaving corridors and retention patches, or with partial cutting or variable retention instead of clearcutting. The jury is still out on how well this ‘new forestry’ is working for wildlife. Intact ecosystems can also help wildlife adapt to change.³⁰⁷ Some animal species are already responding to global warming by breeding earlier,³⁰⁸ migrating earlier, and producing multiple generations per season.³⁰⁹ But some species may not be able to adapt fast enough to keep up with rapid climate change.³¹⁰ Intact ecosystems can soften the impact of climate change to wildlife by slowing the rate of landscape change, moderating microclimates, and providing alternative habitats.³¹¹

1.8.4 Facilitated Migration

British Columbia has a long history, starting in the mid-1950s, of translocating game species from robust populations to southern areas where populations had been extirpated. Consequently there is a data set on the ability of certain species to adapt to these warmer habitats—an early forerunner to what is known as facilitated migration. Facilitated migration is a tool proposed for human-assisted migrations of species like whitebark pine that probably can’t do it on their own. California bighorn sheep (*Ovis canadensis californiana*) are one of the most successful species ever translocated. Having been extirpated from all of their former ranges in the USA by the early 1900s (except for a herd in the southern Sierra Nevada), they were transplanted from the Junction Sheep Range in the Chilcotin into their former ranges in Washington, Oregon, Idaho, Nevada and northern California. This transplant program has been so successful that now California bighorn occupy all their available habitats in the USA.³¹² California bighorns that were transplanted from the Chilcotin to southwestern Idaho gave birth one month earlier than they did on their home range.³¹³

Also, the translocation of gray wolves from northeastern B.C. into Yellowstone National Park, where they had been exterminated early in the 1900s, has re-established a vital component of that ecosystem. Wolves from those transplants and from immigration from the Flathead Valley in the East Kootenay have now spread into northwestern Montana, central Idaho, and even as far west as the Blue Mountains of Oregon. This paper isn’t attempting to deeply explore the issue of facilitated migration but notes the importance of maintaining *in situ* healthy native populations which could have huge value in the future as reservoirs for transplants.

1.8.5 Summary of Resilience and Ecological Adaptation

Intact, functional, natural ecosystems probably are more resilient to climate change than are ecosystems that are fragmented, simplified or degraded by human activities. Resilient ecosystems can regenerate after disturbances, resist and recover from pests and diseases, and adapt to changes in temperature and water availability—including those resulting from climate change. More diverse, complex systems tend to be more resilient; fragmented, simplified or degraded systems tend to be less resilient; and even resilient systems will radically shift if the environment changes sufficiently.

Intact systems tend to be more resilient than degraded systems for several reasons. At the local site level, natural ecosystems create their own sheltering and buffering microclimates, which slow the rate of change and give resident species more time to migrate or adapt. Natural forests in particular play a major role in protecting the quality and quantity of water by buffering the impacts of storms, floods, erosion, drought and rising temperatures. At the broader level, landscapes that are more intact (not fragmented by roads or shifted from natural patterns of habitat by industrial use) may enable populations to adjust to climate shifts by providing safer, less stressful, more functional enclaves for persistence, and linkages for migration.

Natural ecosystems soften the impact of migration lags—slowing the rate of landscape change, moderating microclimates, and providing alternative habitats. For species occupying discrete forest stands or habitat patches, successful migration may require maintenance of within-species gene flow among the stands or patches of ecosystem types. Intact landscapes can facilitate this flow, while fragmented landscapes can impede it.

The different climate scenarios project a wide range of future conditions, so an integrated approach is needed for an on-the-ground, decision-making process about land use that:

- Focuses on maintaining ecosystem and evolutionary processes, including disturbance regimes and nutrient cycles;
- Enhances the capacity of ecosystems to self-adapt and reorganise;
- Focuses on reducing the vulnerability of biodiversity elements to climate change and on making decisions that deal astutely with uncertainty and risk;
- Evaluates what we know about the sensitivity of target organisms and ecosystems to climate (for example, in terms of resilience), about synergism with other threats, and what can be done practically to maintain the viability of species and the integrity of ecosystems in light of multiple threats;
- Maintains or strengthens the resilience of ecological systems, and builds flexibility and responsiveness into our planning and management of them. Healthy ecosystems are the cornerstone of a plan that protects biodiversity and our life support system;
- Reorients conservation efforts from trying to maintain historical species distributions and abundances or the status quo towards: a) maintaining well-functioning, resilient ecosystems of sometimes novel composition that continue to deliver ecosystem services; b) maximising the diversity of native species and ecosystems;
- Determines which ecological zones, ecosystems, and species (including invasive species) are of greatest conservation concern. Brings together ‘species of provincial concern’ under specific ‘zones of concern’ to best implement protection of habitat and make best use of resources;
- Evaluates peripheral species in terms of ecosystem function, genetics and evolutionary potential, and sensitivity/projected response to environmental change;
- Recognizes that species are adapting and moving largely independently as climate changes, that new ecosystems will arise, and that the genetic consequences of change will be as significant as species and ecosystem consequences;
- Applies the concept of stewardship to B.C.’s biota generally, so as to address our endemic species and their habitat, as well as those that have the majority of their global range or population within the province;
- Applies the concept of stewardship to B.C.’s globally significant ecosystem diversity and landscape complexity, and to intact dynamics such as the large-mammal predator-prey and the wild river-salmon-bear-forest systems;
- Focuses attention on selected species that are ecologically critical, regardless of their commonness or rarity. Such focal species would include top carnivores, abundant herbivores, keystone species, and ecosystem engineers;
- Focuses attention on tree species for reasons relating to ecosystem role (structure and function), ecosystem services, carbon dynamics, genetics and life history characteristics, and economic significance;
- Recognizes that, compared to simplified or degraded ecosystems, intact natural ecosystems have a more

diversified portfolio of ecological assets, more heterogeneity and diversity of structure, composition and function, and a more complex network of interactions, thus tend to be more resilient to disturbance and change. Their diversification reduces the risk of unacceptable losses of biodiversity. Such risk cannot be eliminated but it can be managed;

- Allows for different adaptive strategies of species and enables different types of evolutionary processes to continue, by protecting large unfragmented natural areas as well as sanctuaries with connectivity;
- Re-examines the roles of protected areas, buffer zones, connectivity, ‘special’ management zones, and matrix management.

1.9 Planning for Ecological Adaptation

“Biodiversity conservation is not, and should not be, a sole question of the number of taxa in an ecosystem; rather, it must also address the maintenance and function of natural ecological and evolutionary patterns and processes in systems as undisturbed as possible.”³¹⁴

1.9.1 Protected Areas

British Columbia’s parks, conservancies, and other protected areas (for example, ecological reserves) have traditionally formed the foundation of conservation. Climate change action plans should acknowledge and incorporate these protected areas as one of the most important management instruments for climate adaptation, resilience, and biodiversity conservation.³¹⁵ They will continue to be pillars of biodiversity conservation, but the reserve system needs to be enhanced substantially and integrated with more effective off-reserve conservation.³¹⁶ Protected areas will be of increasing importance to help species and ecosystems survive and adapt (‘parks as arks’) to altered conditions, or help species migrate to suitable habitats. They also are important benchmarks and places to monitor and research the impacts of climate change, and will play an increasingly important role in informing society about the causes and consequences of climate change.

Protected areas planning still has not incorporated large-scale climate change.^{317, 318, 319} Fortunately, B.C.’s park system planning attempted (especially in recent decades) to represent and protect—in addition to recreational features—not only contemporary plant and animal communities, but also and more fundamentally the physical components of the province’s landscapes and waterscapes. These physical features include topography and physiography, the different types of bedrock and surficial geology, landforms, and hydrologic systems. The park system is based in large part on physical **enduring features** that will not change much as climate changes, as species sort themselves out and as biological communities reassemble. The mountains, rivers and big lakes will remain, the interior plateaus will persist, morainal blankets and outwash terraces will stay as they are, even as the biota they support changes. The physical landscape is the template for ecosystems, the stage upon which the drama of climate change is playing out.

Consider the ‘bio-geo-ecosystem’ as “a real live chunk of earth space ... a volumetric, layered, site-specific object—such as a lake, a particular landform-based forest, or a more complex (land-water) tract—into and out of which mobile organisms come and go.”³²⁰

Beyond protected areas, enduring features offer a reliable and predictable foundation for conservation planning and resource management in general. Over the last decade, methods for modelling enduring features have advanced significantly and have been applied in a variety of conservation plans as an important surrogate for biological diversity.^{321, 322, 323, 324, 325} The uncertainty of a climate changed future prompted a recent attempt³²⁶ to use enduring features spatial analysis to help delineate areas of high and potentially persistent conservation value, as part of a land use planning exercise in northwestern B.C. The areas selected were partly

defined by high physical variety and rarity, both important enduring elements of a future biologically diverse landscape. Targeting contemporary ecosystems and projecting forward (based on biophysical signatures) to identify and maintain future locations is another use of enduring features in this study.

More work is needed to clarify the role of enduring features models in addressing climate change mitigation questions (for example, where are important second-growth forest carbon sinks?) and adaptation questions (for example, how best to capture the full spectrum of enduring features gradients underpinning expansive functioning ecosystems such as large-mammal predator-prey systems?).

However, in themselves, parks will not adequately protect all of B.C.'s biodiversity in the face of climate change. Protected areas still do not fully or sufficiently represent the physical and biological diversity of the province; the system is skewed towards high elevations and less productive ecosystems. Also, in addition to incomplete representation, most of the parks are too small and isolated to withstand human impacts, let alone climate change. Human activities in the surrounding landscape have inhibited the natural distributions and abundance of wildlife in the long-term.^{327, 328, 329} This is especially true for wide-ranging species such as migratory animals (for example, salmon) or large carnivores (for example, wolf), which require vast areas of water or land as habitat.

Climate change will erode the genetic diversity, contemporary ranges, and current degree of protection of many species and ecosystems. It will draw down B.C.'s natural capital and will reduce ecosystem services. The degree to which these losses can be offset by the occupation of newly suitable habitat is highly uncertain. Improvements and refinements to our system of protected areas could reduce the damage expected in this century. "The spatial distribution of protected areas, particularly between lowlands and uplands, is an important determinant of the likely conservation consequences of climate change."³³⁰ Thus a key question becomes: What is needed to protect biodiversity in a changing world—beyond the incompletely representative 14 percent of the land base that is currently in protected areas? In other words, how much is enough?

1.9.2 How Much is Enough?

Meta-analyses of land use planning for conservation have found that the protected proportion of a region's land base, necessary to meet these conservation objectives, lies between 25 percent and 75 percent.^{331, 332} The median protected area recommendation lies above 50 percent.^{333, 334, 335} From a scientific perspective, a single figure is too simplistic, but 50% has been selected by some jurisdictions as a target (for example, Governments of Ontario and Quebec, for the northern parts of those provinces). Half of the world's natural ecosystems have already been degraded or transformed, so as a starting point, the appropriate answer to 'How much is enough?' is really 'What's left?'

In British Columbia, we don't have accurate information about which ecosystems remain in an undegraded state and we need to address that knowledge gap. Further, conservation planning to date has not kept pace with the shifting scenarios of climate change.^{336, 337, 338} For that and other reasons, conservation biologists have moved beyond general statements about how-much-is-enough thresholds?³³⁹ Some scientists argue that the precautionary approach would entail the maximum possible protection of remaining intact natural areas.^{340, 341} Thus a more legitimate question is: Given a decision by society to protect a certain proportion of the landscape (for example, 50 percent), what areas can best achieve biodiversity protection and other goals, such as carbon retention? (These issues are addressed in Part 2.)³⁴² Alternatively, one could analyze how various sizes of potential reserve networks would affect attainment of biodiversity and carbon goals. Framing the question in this way disentangles policy decisions from those best addressed by technical analyses, and thus reduces the politicization of science.

1.9.3 Beyond Preservation: Managing the Matrix

“The risk management strategy of diversification offers the best hope for designing conservation strategies that reduce the probability of human-influenced biodiversity losses.”³⁴³

The other major shift in conservation planning is away from confining stewardship responsibilities to protected areas and corridors, to broadening that responsibility across the landscape, regardless of tenure and landholder—acknowledging the importance of maintaining matrix habitats, that is, the land outside of protected areas.^{344, 345} Data show that the type of land cover between protected areas strongly affects the sensitivity of species to the impacts of living in small isolated patches of protection. In other words, how we manage the entire landscape has more effect on biological diversity than the size of protected areas. This implies that land managers must accept the responsibility for conservation of biological diversity across every hectare of land that they manage.³⁴⁶ Conservation must occur at multiple scales and multiple jurisdictions. Conservation must be more than setting aside parks on a small percentage of the landscape. Climate change highlights the urgency of adopting this shift in thinking, for Nature is on the move.

1.9.4 Status of Conservation Legislation in B.C.

Some small steps have been made towards applying the concept of conserving across the matrix in B.C.^{347, 348} The province has introduced a Conservation Framework to implement a much-needed multi-sector framework for action, but it falls short in most other respects, with no commitment to new tools, incentives, legislative reform, or enforcement mechanisms to make it work.³⁴⁹ Existing legislation falls short in several areas, which will now be discussed.

The British Columbia Conservation Data Centre develops lists that enumerate species and ecosystems at risk and categorize their conservation status based on rarity and risk. Current approaches to the problem of escalating biological impoverishment seldom extend the study beyond such lists, which do little to protect and conserve species or ecosystems, or to encourage the study of currently abundant species that may become vulnerable in a changed climate. There are no laws or policy in place to help species adapt *in situ* or move to where they can survive.

The federal Species at Risk Act (SARA) has limited application in B.C. Its strictures against killing, harming, and harassing species at risk apply automatically only to aquatic species and migratory birds, and on federal lands; and its protections against destroying critical habitat apply automatically only to aquatic species and on federal lands.³⁵⁰ Federal lands only make up about 1 percent of B.C.³⁵¹ And although SARA allows for the federal government to apply protections to other species under the so-called ‘safety net’, the federal government has never done so. Thus the federal SARA leaves primary responsibility for protecting the majority of species at risk in B.C. to the province.

B.C. currently uses two policy instruments for protecting species at risk, the Identified Wildlife Management Strategy (IWMS) for forest-dependent species (under the Forest and Range Practices Act; FRPA) and an amended Wildlife Act for other species at risk. However, only 3.2 percent of the province’s species at risk have been included under one of those two instruments.³⁵² The IWMS has a 1 percent policy cap, meaning it must not have more than a 1 percent impact on timber supply, which is at best unnecessary and is at worst a serious constraint on the ability of some forest districts to protect species at risk.³⁵³ Under the FRPA, protective measures for wildlife can be implemented only without ‘unduly’ reducing the supply of timber from British Columbia’s forests.

Others have similarly commented on the negative implications of the cap for forest biodiversity protection. For example, the Forest Practices Board (FPB) noted in its 2004 report³⁵⁴ that the limit is not just 1 percent of the total timber supply but of ‘short-term’ timber supply, (which considers only the area of mature, that is, over 80 years of age, timber.) The effect of that interpretation is very significant, especially on the

south coast where most timber is immature second or third growth. For species like the marbled murrelet (*Brachyramphus marmoratus*), it effectively prevents conservation of their habitat.

More recent reports highlight the same problems.³⁵⁵ British Columbia's Wildlife Act still lists only four species at risk. While this protects those four species from hunting and killing, it provides no habitat protection for them. Seventy-two species at risk are currently listed under the Identified Wildlife Management Strategy (IWMS) of the Forest and Range Practices Act (FRPA), but the 1 percent cap and the regulatory requirement that biodiversity protections not 'unduly reduce the supply of timber' are still in place.

An effective conservation strategy needs to reflect a greater commitment to biodiversity protection through legal reform, providing more incentives, and prioritizing species and ecosystems for conservation over a variety of tenures, including private land. The following elements articulated in a proposed Species and Ecosystems Protection Act (SEPA) would address some of these needs.³⁵⁶

- Create a species/ecosystem listing body that could proactively assess the risk posed by climate change to the long-term viability of species and ecosystems;
- Devise a meaningful recovery planning process for listed species and ecosystems, with due regard to the implications of planning decisions and different scenarios of climate instability;
- Impose a mandatory legal requirement for habitat protection;
- Provide information on the type and extent of connectivity required between protected areas to maximize resilience.

Conservation planning in B.C. needs to draw upon the best available science, for finding practical solutions to conserving biodiversity during climate change will be challenging and complex.

1.9.5 Managing the Forest Matrix

“Good forest management in a time of rapidly changing climate differs little from good forest management under more stable conditions, but there is increased emphasis on protecting climatic refugia and providing connectivity”³⁵⁷

Now more than ever, there is recognition that forest management in B.C. needs fundamental rethinking and a transformed approach. Although forests in general have proved resilient to past changes in climate, today's fragmented and degraded forests are more vulnerable.³⁵⁸ The increasingly acute threat to our forests is not climate change acting in isolation, but rather the combination of climate change and continuing overexploitation, fragmentation, conversion and degradation by humans.³⁵⁹

The underlying philosophy of the provincial regulatory system for forestry is one of 'constrained resource extraction.'³⁶⁰ Because environmental measures place constraints on tenure holders' rights to their portion of the allowable annual cut allocated through licence, policy has privileged these economic interests. For example, default caps on timber supply impacts are put in place when environmental measures are implemented, limiting the scope of any changes in management. Small adjustments or 'tinkering' with the current management approach, whether to conventional seed transfer guidelines, silvicultural prescriptions, wildlife tree guidelines or tiny old-growth management areas, are inadequate responses to climate change. This has already proven to be the case with conventional tree-breeding and seed transfer guidelines for key species like lodgepole pine.^{361,362} There is a recognition that managing forests as complex adaptive systems would increase the probability of maintaining their resilience during climate change. The Ministry of Forests and Range specifically has identified resilience as the focal attribute in addressing environmental and socioeconomic change.^{363,364} However, the limitations of current policy mean contemporary forest practices do not adequately address the current crisis in declining biodiversity, let alone reflect anticipated trends from climate change.

Recent assessments of forest management,^{365,366,367} in light of climate change, have consistently identified the

Connectivity among protected areas is essential to provide space for nature to self-adapt, to adjust to the new conditions brought on by climate change.

Photo Wayne Sawchuk



principles of diversifying forest structure, maintaining complexity and microclimates, embracing environmental variability and uncertainty, decreasing fragmentation, extending rotation lengths, and addressing as wide a variety of ecosystem components (not just trees and vertebrates) and functions as possible.

Complexity is an intrinsic attribute of forest ecosystems, the key to ecosystem functions and processes such as biodiversity, productivity, adaptability to altered conditions, and resilience. Managing forests as complex adaptive systems makes sense in light of changes in climate and other environmental conditions, changes in society's expectations of forests and foresters, and changes in the economics of forestry, forest conservation and the evaluation of ecosystem services.

Noss³⁶⁸ discusses what he means by good forest management, and outlines the land-use and management practices likely to maintain forest biodiversity and ecological functions during climate change:

- “representing forest types across environmental gradients in reserves;
- protecting climatic refugia at multiple scales;
- protecting primary forests;
- avoiding fragmentation and providing connectivity, especially parallel to climatic gradients;
- providing buffer zones for adjustment of reserve boundaries;
- practising low-intensity forestry and preventing conversion of natural forests to plantations;
- maintaining natural fire regimes;
- maintaining diverse gene pools;
- identifying and protecting functional groups and keystone species.”

Puettman et al. discuss the need to practice the following principles in actively managed forests:

- develop and maintain heterogeneity in ecosystem composition, structure, and function, both within forest stands and, at a landscape level, among stands;
- allow stands to develop somewhat idiosyncratically, within a spacious envelope of possible conditions, rather than trying to constrain all of them within a narrow set of successional pathways; acceptable species; stocking standards; regular spacing; uniform tree and crown sizes; or textbook diameter distributions.³⁶⁹

Although incremental progress towards some of these practices has occurred especially over the past 15 years or so, they do not reflect most past and current forest management in British Columbia. The provision of goods and services other than wood is still mostly treated as a constraint to timber production.

“If biodiversity protection is a principal goal, then we need to state it as an objective for management and not a constraint.”³⁷⁰

1.9.6 Summary of Planning for Ecological Adaptation

Climate change challenges conventional approaches to nature conservation. Projected climate changes are of a magnitude and character to have huge ramifications for genomes, populations, species, communities, ecosystems, and landscapes. On top of this, the uncertainty about the rate, dimensions, and projected impacts of climate change makes managing for the future even more difficult. Existing strategies for conserving nature and biological diversity are not sufficient. Some existing management tools remain effective, some need major modification, and new approaches must be developed so as to enhance ecosystem resilience.

While existing parks continue to be pillars of a nature conservation strategy and act as ‘arks’ and ecological benchmarks, most are not big enough to sustain biodiversity on their own. The reserve system needs to be enhanced substantially and integrated with more effective off-reserve conservation. The question of ‘how much is enough’ land base protection to support biodiversity has become more complex because of inadequate understanding of the shifting scenarios of climate change and the extent to which landscapes are already degraded. Maintaining the integrity and connectivity of entire landscapes is now more important than ever.

Conservation biology research has long pointed out that a constellation of protected areas is insufficient to maintain biodiversity values, that it is also necessary to ensure that the lands in between—the matrix—are not hostile to species on the move. Climate change underlines the necessity of a nurturing matrix. Enabling species movements through the broader landscape will be key to maintaining as many species as possible. Conservation of biodiversity must take place at multiple scales in all jurisdictions and be the responsibility of everyone.

Key recommendations for managing the forest matrix include protecting primary forest, providing buffers to protected area boundaries, reducing conversion of old-growth (or primary) forests to industrially managed forests or natural forests to plantations, and providing connectivity. Contemporary management must shift to improved forest management practices that strive to maintain forest biodiversity and ecological functions by:

- maintaining and restoring fully diverse forests, with structure and complexity at all scales, from the stand to the landscape level,
- embracing environmental variability and uncertainty,
- decreasing landscape fragmentation,
- extending rotation lengths to restore diversity and add structure in landscapes where it has been lost,
- addressing as wide a variety of ecosystem components (not just trees and vertebrates) and functions as possible, and
- reducing pressures on keystone and foundation species.

In the past, management approaches based on the principles of conservation biology have been suggested or implemented to limited degrees on some areas of British Columbia’s forested land base. The predicted consequences of climate change now bring an additional and urgent impetus for their application. Planning with the goal to achieve increased landscape resilience in the face of climate change is novel—and will require significant shifts in approach. It is time for British Columbia to embrace these concepts and become a global leader in modern forest management.

Part 2: Biodiversity, Climate Change and Mitigation



Photo: iStock

2.1 Importance of Ecological Mitigation

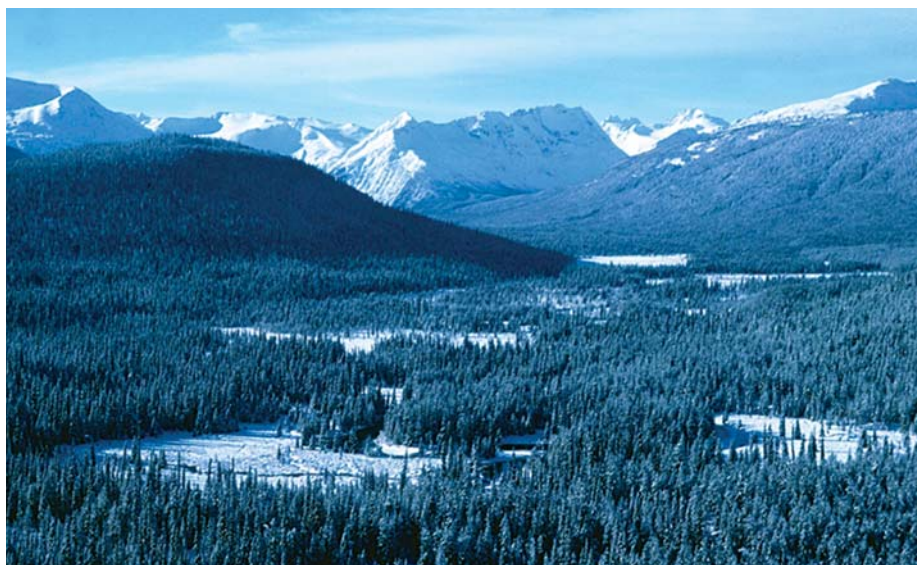
As outlined in Part 1, the conservation and restoration of B.C.'s natural ecosystems and biodiversity is the best risk-management approach for adaptation to climate change and, as such, can stand alone as a key climate action strategy. The conservation argument becomes even more compelling when combined with the huge benefits of a conservation strategy for ecological mitigation through: 1) protection of the carbon sink and sequestration functions of ecosystems; 2) immediate avoidance of emissions caused by deforestation and/or degradation of forest carbon stocks; and 3) expansion of sinks through ecological restoration, to enhance carbon sequestration and storage in the long term.

Given the internationally identified need to immediately reduce greenhouse gas (GHG) emissions, any potentially effective strategies must be seriously considered. Both technological mitigation and ecological mitigation will be required.^{371, 372, 373} Technological mitigation aims to reduce emissions of carbon through alternative technologies, such as carbon capture systems and alternative energies. Ecological mitigation aims to reduce emissions through avoided degradation/deforestation, and to increase the size of the carbon sink and annual sequestration through ecological restoration.³⁷⁴

2.2 Natural Capital and Ecosystem Services

B.C.'s forests and grasslands, lakes and rivers are capital assets that provide vital goods such as clean water, food, forage and timber; life support services, such as air and water purification, nutrient cycling and waste treatment; and life-enriching benefits, such as recreational opportunities, tourism assets, nature education, beauty and serenity.

Ecosystems also have value in terms of the conservation of options for the future, such as genetic diversity for adaptation and evolution in changing environments, or resilient forests for carbon stewardship in a world being overwhelmed by CO₂. Natural capital is the heritage of ecosystems that provide Earth's life support



B.C.'s forests constitute a massive carbon recycling system, avoiding its depletion will assist our efforts to manage CO₂ levels.

Photo Jim Pojar

system. These biological underpinnings or 'green infrastructure' ultimately produce all the ecosystem services on which humans depend.³⁷⁵

The Millenium Ecosystem Assessment³⁷⁶ assessed the consequences of ecosystem change for human well-being and established a scientific basis for conservation and sustainable management of ecosystems. It also developed a classification of ecosystem services, which can be applied to B.C. ecosystems.³⁷⁷ The ecosystem services involved in the carbon cycle are linked directly to climate regulation. Carbon is fixed by living plants; cycled, stored, and released by living and dead plants and things that consume them, by decomposing organic material on the ground, and by organic matter in the soil.

Until recently ecosystem services were treated as virtually inexhaustible and 'free'.³⁷⁸ A 1997 study was the first to try and put a price tag on the biosphere, estimating the value of the asset of global ecosystem services as between \$18 and \$61 trillion US dollars, about as much as the global gross national product.³⁷⁹ While there was considerable debate regarding the data and methods, there was no debating the central finding that ecosystem services are of crucial importance to humanity and that they underlie every country's economy.^{380, 381, 382}

No comprehensive accounting of B.C.'s natural capital and ecosystem services exists. However, a recent assessment of the Mackenzie River watershed (which includes all of northeastern B.C.) estimated the non-market value of this boreal area's natural capital as Cdn\$484 billion per year (about \$2,800 per ha), 11 times the annual market value of its natural resources (that is, timber, oil, natural gas, minerals, and agricultural soils) and non-resource sectors.³⁸³ Carbon storage and sequestration were estimated to be worth \$250 billion in 2005, 56 percent of the total non-market value of ecosystem services. Again, the methods are not fully resolved but these figures indicate the economic importance of ecosystem services.

2.2.1 Summary of Natural Capital and Ecosystem Services

B.C.'s forests and grasslands, lakes and rivers are capital assets that provide vital goods, life-support services and life-enriching benefits. A preliminary accounting of B.C.'s ecosystem services, including adaptation and mitigation services (that is, carbon storage and sequestration), suggests the huge importance of our natural legacy.

2.3 Role of Ecosystems in Climate Change Mitigation

Protection of healthy ecosystems is vital to the conservation of biodiversity and maintenance of ecosystem services. It is also vital to the long-term stewardship of carbon. Natural terrestrial ecosystems play two major roles in the carbon cycle. Nature removes carbon and nature stores carbon. B.C. ecosystems store huge amounts of ‘living’ and ‘dead’ carbon,³⁸⁴ especially in our coastal old-growth forests, which along with the world’s other temperate rainforests, store the largest amounts of carbon per hectare on the planet.^{385, 386} Through photosynthesis, the primary producers (mostly plants) remove (fix) CO₂ from the atmosphere. After accounting for releases to the atmosphere, the net amount of carbon absorbed **annually** is termed carbon sequestration, which is synonymous with net ecosystem production.³⁸⁷

Ecosystems store the carbon primarily as:

- wood and other biomass (living organic matter) above-ground (stems, branches, leaves, bryophytes and lichens)
- below-ground wood and other biomass (roots)
- necromass (litter, woody debris), and
- organic carbon in the soil.

Ecosystems release CO₂ back into the atmosphere when trees, other vegetation, and other organisms living in ecosystems respire, burn or decay.

Globally, forests, grasslands, wetlands and tundra function as large terrestrial reservoirs of carbon, part of the Earth’s feedback system that until recently maintained fairly stable concentrations of atmospheric CO₂. Even now, the biosphere (the global aggregate of aquatic—especially oceans—and terrestrial ecosystems) removes 50 to 60 percent of human-caused greenhouse gas emissions (fossil fuel and land use emissions), curbing more intense global climate change.³⁸⁸ Forest ecosystems contain more than half of the world’s terrestrial carbon, and account for about 80 percent of the carbon exchange between terrestrial ecosystems and the atmosphere.³⁸⁹

2.3.1 Forested Ecosystems of B.C.

Forests also play a dominant role in the carbon budget of British Columbia. Well over half of the province is forested. The carbon stored in the trees, roots and soils of these forests averages 311 tonnes per ha. In total 18 billion tonnes of carbon are estimated to be stored by B.C.’s forest ecosystems, nearly 1000 times the province’s annual emissions of greenhouse gases.³⁹⁰

There is a strong link between ecosystem conservation and carbon stewardship. One-fifth of the world’s carbon emissions come from deforestation and land degradation, primarily in the tropics. B.C.’s Greenhouse Gas Inventory Report³⁹¹ indicates that timber harvesting (72.7 MtCO₂e) and slash-burning (8.2 MtCO₂e) were responsible for a combined 80.9 MtCO₂e GHG emissions in 2007 alone, exceeding the carbon emissions from all other sectors in B.C., such as energy associated with transportation (Fig. 9). BC does not include forestry emissions in its official GHG emission inventory in accordance with Canada’s decision under the Kyoto Protocol. Nor are emissions from forestry addressed by the Province’s Climate Action Plan. Nevertheless, even if one accounts for the fact that some carbon is stored in long-lived wood products, logging is still a massive source of carbon emissions in the province. These emissions cannot be simply offset by planting new forests (afforestation) or restoring logged forests (reforestation) because it takes a long time for forests to be established, grow and mature. Thus avoiding the destruction and degradation of carbon-rich ecosystems in BC, such as old-growth forests and peatlands, has a pivotal role in carbon storage and in helping meet our short-term GHG mitigation objectives.

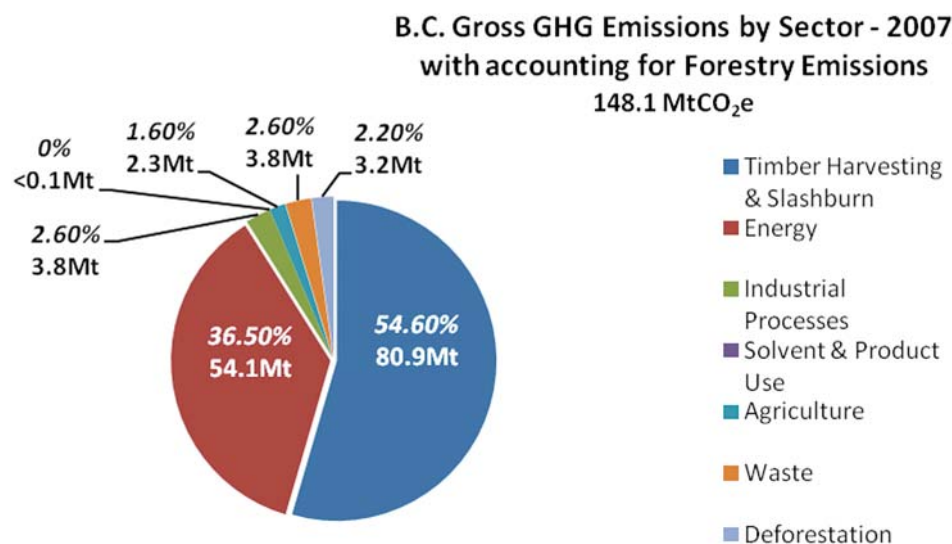


Figure 9. B.C. Gross Greenhouse Gas Emissions by sector in 2007 with accounting for forestry emissions. Adapted from BC Greenhouse Gas Inventory Report, 2009.³⁹²

Note 1: The chart displays gross sector emissions from human activity—totals rounded to 1 decimal place. Excluded from this analysis are carbon emissions from wildfires and insect infestation, the decomposition of dead and decaying organic matter such as dead trees, vegetation and soils, and emissions associated with croplands and wetlands.

Note 2: Forestry emissions accounted for include timber harvesting and slashburning only.

Note 3: Net emissions from forestry would be less than the gross emissions depicted here if one accounts for removal of carbon from the atmosphere through afforestation, reforestation, net primary production (NPP), or carbon storage in wood products.

2.3.2 Non-Forested, Permafrost and Oceanic Ecosystems

Wetlands

Wetlands include bogs, fens, swamps, marshes, riparian zones and shallow open water. In most of British Columbia, wetlands are frequent but generally small. Three well-known, unusually large southern wetlands are Burns Bog and the marsh/fen complexes of the Creston valley and upper Columbia valley.³⁹³ Though they sequester mostly in anonymity, the exceptionally large wetland complexes of the Fort Nelson Lowland, the Hecate Lowland (central and north coast), and the Argonaut Plain (northeast Haida Gwaii) actually dominate these regional landscapes.

These three northern wetland complexes are mostly peatlands, carbon-rich wetland ecosystems with massive deposits of peat at least 40 cm thick. Peatlands have greater soil carbon density per square metre than any other terrestrial ecosystem.³⁹⁴ B.C.'s peatlands cover about 6 percent of the province—mostly in the north and on the outer coast—and are estimated to store 6.8 billion tonnes of carbon and to sequester about 1.5 million tonnes of carbon per year.³⁹⁵ The future magnitude and direction of peatlands' influence on climate are uncertain.³⁹⁶ In particular, it is unclear how long northern peatlands can continue to function as net carbon sinks, given their sensitivity to drought, water table drawdown, melting permafrost, and especially surface disturbance from oil and gas exploration and development, and the resultant emissions of CO₂ and CH₄. This makes a strong argument for protecting peatlands, to help them maintain existing stores of carbon.

Grasslands

B.C.'s grasslands sequester large amounts of carbon in their soils, much of which is released into the atmosphere when these grasslands are cultivated or converted to orchards, vineyards or housing developments. Overgrazing and other degradation leads to subsequent invasion by exotics, which simplifies and reduces their sequestration abilities, biodiversity values, and adaptation capacity. Grasslands cover a small part of the province and their contribution to the carbon economy is also relatively small. But they

make a disproportionately large contribution to the biodiversity of B.C.³⁹⁷ and, in the face of numerous threats ranging from excessive livestock grazing to urbanization, deserve maximum protection.

Permafrost Ecosystems

Thawing permafrost results in the microbial decomposition of previously frozen organic carbon. The liberation of this carbon (as CO₂ and CH₄) is one of the most significant potential positive feedbacks from terrestrial ecosystems to the atmosphere and to a warming climate.³⁹⁸

Thawing of discontinuous permafrost could be brought on by increases in air temperatures of only 1 to 2°C.³⁹⁹ Intact forests, peatlands, and to a lesser degree tundra provide permafrost with some insulation from warm air temperatures. Thus, by maintaining such ecosystems and their vegetation cover, melting of permafrost could be delayed several decades.^{400, 401, 402}

Northern British Columbia is within the zone of sporadic permafrost, with some local concentrations especially in the Fort Nelson Lowland. This permafrost is already on the edge and, given the rapid regional warming underway, could disappear relatively soon. But maintaining intact forest and peatland cover could slow greenhouse gas emissions for several decades at least. Unfortunately the Fort Nelson area (and northeastern B.C. in general) has had a sharp increase of industrial activities over the past 25 years, from logging to natural gas exploration and development. The environmental impact is unprecedented in B.C. and a recent study gives some idea of the cumulative effects of the industrialization of these landscapes.⁴⁰³ Climate warming aside, thawing of permafrost in this area can be triggered by any disturbance of the vegetation cover, whether it is due to logging, fire, roads, railroads, seismic lines or pipelines.

Alplands

The alpine zone in B.C. also has sporadic permafrost, especially in the northern mountains and high plateaus. Permafrost is probably less susceptible to thawing at high elevations than at low elevations, at least in northern B.C. Even so, permafrost is already melting locally at high elevations, and has been implicated in some large landslides.⁴⁰⁴ The alpine zone is not under wholesale industrial assault, but its permafrost terrain can be severely disturbed locally by mining exploration and development. Some proposed wind power projects could also pose a threat, for example to permafrost ecosystems in the northern Rockies and on the Kawdy Plateau.

Oceans and Marine

Our oceans are one of the greatest natural sinks for CO₂. Since pre-industrial times, oceans have taken up more than a third of all human-produced CO₂ emissions, most of which is held in the ocean's surface.⁴⁰⁵ These carbon-saturated surface waters are transported and mixed to depths where the CO₂ can be sequestered. However, as atmospheric concentrations of CO₂ rise, surface waters in many areas will become less able to absorb it. The alteration of global currents due to climate change is exacerbating the problem, further reducing the capacity of oceans to perform their critical natural service of absorbing CO₂.

But oceans are still absorbing CO₂—at a price. When seawater and CO₂ mix, carbonic acid is produced. The natural alkalinity of the oceans, due to calcareous minerals such as calcite and aragonite, buffers (or neutralizes) this acid. But with the absorption of ever-increasing amounts of CO₂, the pH of our oceans is declining, and these neutralizing minerals are rapidly being depleted.⁴⁰⁶ This is happening now—a large part of the North American continental shelf is already affected by acidification. A multitude of marine organisms, including corals, shellfish, and some plankton, depends on calcite and aragonite to build their calcareous structures.⁴⁰⁷ As acidification increases, their ability to grow will suffer, and their shells and skeletons will simply dissolve. The implications of ocean acidification include direct and indirect reductions in food for humans and other species, both marine and terrestrial. Acidification is only one problem of many

that our oceans face as a result of increasing concentrations of CO₂ in the atmosphere. Other impacts include temperature increases, salinity changes, low-oxygen zones, changes in hydrology and precipitation, and changes in currents.

Terrestrial ecosystems are inextricably linked with marine ecosystems. Healthy forests can help take the pressure off our oceans by absorbing CO₂. Mitigation of carbon on land is one of the few available solutions for preventing further damage to our oceans.

2.3.3 International Recognition of Nature's Role

Until recently, most climate change strategies have focused on avoiding emissions of ancient carbon—that is, reducing the use of fossil fuels. However, there has been a huge surge of attention from the international scientific community on the vital role nature itself plays, both in mitigation and in adaptation to climate change.^{408, 409, 410, 411, 412}

International climate change initiatives have typically focused on technological mitigation of ancient carbon. There has also been substantial investment in looking for technological solutions of artificial sequestration, for example, pumping CO₂ down old oil wells, although the technology is unproven and some researchers are increasingly skeptical of its benefits.^{413, 414} With Poznan and Copenhagen climate talks pointing to worst case scenarios, it now appears clear that no matter how successful technological mitigation is, the current mechanisms forcing climate change are so advanced that it won't be enough to prevent destabilization of contemporary ecosystems.⁴¹⁵ And if we do not significantly reduce emissions of all greenhouse gases, climate change in the long run will probably overwhelm the resilience of most ecosystems.⁴¹⁶

The November 2008 report from the Secretariat of the Convention on Biological Diversity (CBD) states as their number one finding that: “Maintaining natural ecosystems (including their genetic and species diversity) is essential to meet the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) because of their role in the global carbon cycle and because of the wide range of ecosystem services they provide that are essential for human well-being.”⁴¹⁷ The CBD identifies four benefits of living carbon stewardship: sequestering carbon, avoiding emissions, managing resilience, and maximizing stocks and flows of ecosystem services.

On December 8th, 2008, the UNFCCC at the climate talks in Poznan, Poland committed to a protocol for forest protection measures known as Reduced Emissions from Deforestation and Degradation (REDD). This protocol was due to be implemented in Copenhagen in December 2009 to augment existing protocols under Kyoto for Afforestation, Reforestation and Restoration (ARR) and Improved Forest Management (IFM). Also on December 8th, 2008, the government of British Columbia passed its own enabling tool of an Emission Offset Regulation that will set the framework for forest conservation to be considered for carbon emission offsets—in readiness for the international protocol. California, our lead partner in the Western Climate Initiative (WCI), has already developed Forest Protocols for REDD and IFM type projects, and completed its first sale of emission reductions through a combination of carbon activities in the Van Eyck, Garcia and Lompico Forest Projects.⁴¹⁸ These transactions are the first of their kind in the WCI, and B.C. has the initial legal framework in place to follow suit very quickly. The North American Forest Carbon Standards are in draft form with carbon conservation projects, as are the international Voluntary Carbon Standards (VCS) that apply now to Canada.

The recent proliferation of reports and frameworks for valuing carbon and ecosystem services in natural forests and ecosystems in B.C. points to the rising recognition of the role of forest conservation in international agreements.⁴¹⁹ The protection of nature and ecosystem services (including the sequestration of carbon) now has an emerging regulatory framework. The different forest carbon activities (ranging along a continuum from ARR—afforestation, reforestation and restoration—through Improved Forest Management to REDD) are described in all the various emerging standards and protocols.⁴²⁰ It is beyond the scope of

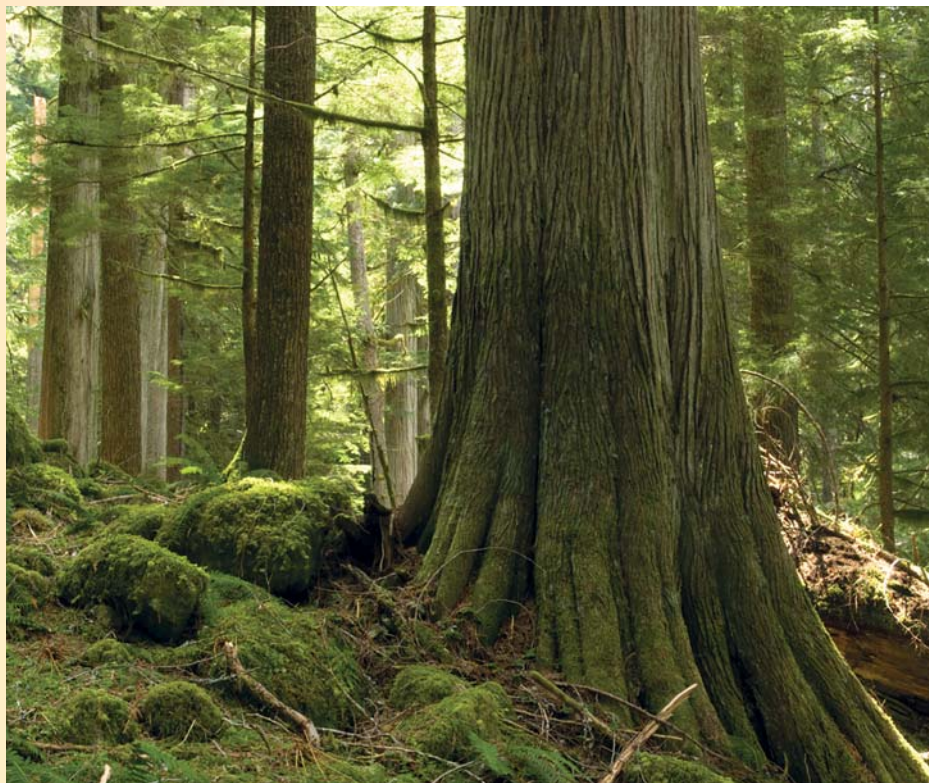
this report to cover their rapid development or their methodologies. These carbon activities are described in detail in Hebda and Brinkman.⁴²¹ Until recently, policy hadn't addressed living carbon because the issue of how to quantify carbon within dynamic ecosystems wasn't resolved. However, many now recognize the opportunity to integrate carbon management into forest management with the additional benefit of improving management for biodiversity and adaptation. Increasing discourse around forest policy reflects this recognition.

2.3.4 Summary of Role of Ecosystems in Climate Change Mitigation

Ecosystems naturally affect the amount of CO₂ in the atmosphere by playing a central role in the carbon cycle. Plants capture CO₂ from the atmosphere and store it as wood or other plant matter. Decomposition results in additional storage in soils and in release of some CO₂ back to the atmosphere. Because ecosystems both absorb and release CO₂, the relative balance between the two processes determines whether a particular ecosystem is a net carbon source or a sink. Depending on how they naturally function, and how they are managed, ecosystems can therefore either contribute to or reduce greenhouse gas emissions and climate change.

Ecosystems—especially forests and peatlands—play a dominant role in the carbon cycle of British Columbia. Grasslands and alplands also have significant roles. Well over half of B.C. is forested. The carbon stored in the trees, roots and soils of these forests averages 311 tonnes per hectare. Old-growth forests steadily accumulate carbon for centuries and store vast quantities of it, up to 1100 tonnes per hectare in our temperate rainforests—some of the highest storage capacities in the world. B.C.'s forest ecosystems are estimated to store 18 billion tonnes of carbon. Large pulses of CO₂ are released when forests are cleared or disturbed by logging, wildfire, or outbreaks of insects and diseases.

There is a strong link between ecosystem conservation and carbon stewardship. One-fifth of the world's carbon emissions come from deforestation and land degradation, primarily in the tropics. B.C.'s Greenhouse Gas Inventory Report indicates that timber harvesting (72.7 MtCO₂e) and slash-burning (8.2 MtCO₂e) are



Forests, wetlands and grasslands play significant roles in the carbon cycle.

Photo (above) Geoffrey Holman, (left) Timothy Epp

a massive source of carbon emissions in the province. These emissions cannot be simply offset by planting new forests (afforestation) or restoring logged forests (reforestation) because forests take a long time to establish, grow and mature. Thus stewardship of carbon-rich ecosystems in BC, such as old-growth forests and peatlands, has a pivotal role in carbon storage and in helping meet our short-term GHG mitigation objectives. BC should establish emission reduction targets for logging as a complement to the ambitious targets that the province has already set for other emission sectors (including deforestation, agriculture, energy, etc.).

Keeping ecosystems healthy and intact conserves living carbon, which in turn generates and stores dead carbon as various forms of organic matter. Factoring the enormous though variably secure carbon storage in B.C. ecosystems into management planning will be a key strategy. Conserving nature, as part of a comprehensive Climate Action Plan, is already recognized by the international scientific community in commitments to protecting carbon sinks and encouraging mitigation through avoided deforestation and degradation as well as ecological restoration.



Newly planted trees cannot quickly recoup the stock of carbon lost due to logging, recovery takes a long time and may never attain original levels of carbon storage.

Photo George Clerk

2.4 Changing Policy in Forest/Carbon Mitigation in B.C.

The values we hold for our provincial forests have been in transition over the last three decades. In recent years the discourse has intensified, largely because of the increasing awareness of the role of forests as carbon sinks, reflected in emerging market values for standing trees and ecosystem services.⁴²² However, policies and practices are slow to get out of the gates for historical, institutional, and philosophical reasons. B.C. forests traditionally have been managed for timber production. Industry has been understandably resistant to move away from business-as-usual in timber production, in part because the economic argument for forest carbon and ecosystem services is still nascent in Canada. In the absence of a transparent, replicable, full-cost accounting system for carbon—based on all carbon emissions from all sectors under different scenarios projected over the next 100 years—the policy debate has stalled over several research gaps:

- Data on the dynamics of carbon through its full cycle from forest to mill to market, with related questions of: How much carbon is stored in wood products? And what is their value as substitutes for higher carbon-intensive building materials (substitution argument)? How much carbon is stored in landfills as discarded wood products?
- Data on rates of carbon sequestration for different aged forests and different types of forests with questions such as: Do young forests sequester more carbon than old forests? Are some forests sources and some sinks? Should we be converting the forests that are sources of carbon to wood products?
- Appropriate methods for measuring carbon in different carbon pools, with questions such as: How much carbon is stored in soils and dead wood and the other different carbon pools? Can we quantify carbon/forest/atmosphere dynamics without adequate data on carbon in soils and dead wood?

In many instances, the data required for accurate accounting do not exist and the research gaps in forest/carbon/atmosphere relationships have slowed the adoption of carbon management activities in B.C. As Greig and Bull point out: “In political science terms, it [policy debate] represents the tensions between top-down and bottom-up planning in developing options for how we manage forest resources for carbon.”⁴²³ It also reflects a societal shift in how we value a natural forest versus an industrially managed forest and a standing tree versus a felled one. The following section attempts to answer these inter-related questions over forest/carbon dynamics and to indicate the direction that science and ultimately policy appear to be heading with regard to forests and carbon.

2.4.1 Summary of Changing Policy in Forest/Carbon Mitigation in B.C.

Carbon stewardship policies and practices in B.C. have been slow in coming for historical, institutional, and philosophical reasons. Traditionally, B.C.'s forests have been managed for wood production, and the economic arguments for forest carbon and ecosystem services are relatively new in Canada.

Policy discourse has been stalled over research gaps in carbon/forest dynamics, gaps that prevent a full understanding of what form of forest management provides the best atmospheric benefit. Questions have focused on isolated elements of the carbon life cycle. Do young replacement forests absorb carbon more rapidly than old forests? What are the immediate carbon impacts of converting primary forests to plantations? Are trees put to better use in wood products or in bioenergy, as a substitute for higher carbon-intensive building materials and fuels, or left growing to absorb and store carbon? Are forests net sinks or sources of carbon? Is carbon storage in forests a permanent solution? These questions have been difficult to answer in the absence of a full life-cycle analysis of carbon under different scenarios, but consensus is emerging on many points, as noted in the next section.

2.5 Emerging Research into Forest/Carbon Dynamics

2.5.1 Young Forests versus Old Forests?

The issue of carbon sequestration and carbon storage by young forests and old forests has attracted much attention and study as well as some conflicting results and interpretations.⁴²⁴ The traditional forestry view has been that old forests are at best carbon neutral because old trees grow more slowly than young trees, and tree death and decomposition become more dominant processes in old forests, therefore net annual carbon uptake (that is, the carbon removed from the atmosphere) declines in old forests. Net carbon uptake has a complex relationship with stand age. Review papers show that annual net carbon uptake (sequestration) is generally low or negative in forests less than 20 years old (because of high rates of decomposition following stand-initiating disturbances), reaches a peak rate in intermediate-aged forests (that is, 30 to 120 years), and declines but reaches equilibrium or remains positive in forests older than 120-160 years.^{425, 426, 427, 428, 429, 430, 431, 432, 433}

Recent research of carbon sequestration in forests in some ecoregions of Oregon and northern California show positive trends in net carbon uptake by old stands (more than 200 years old).⁴³⁴ The uptake might be enhanced because of significant growth of understory trees due to fire suppression. However, it is estimated that total carbon stocks could theoretically increase 46 percent if these forests were managed for maximum carbon storage with no stand disturbances. Given that B.C. has substantially higher proportions of wetter,

Logging releases lots of carbon to the atmosphere while temporarily removing one of the major natural engines of carbon uptake and storage.

Photo iStock



cooler ecoregions, with low disturbance regimes, the data run counter to the traditional forestry view. There is still much work to be done to verify uptake figures, but both temperate and boreal forests can have positive net annual carbon uptake well into old age.^{435, 436, 437, 438}

More significant than uptake is storage. Old forests not only accumulate carbon, they also have tremendous storage capacity and volume that build annually. Theoretical models suggest that forests continue to operate as moderate to strong carbon sinks, because over time they accumulate large amounts of dead carbon as slowly decomposing organic matter in coarse woody debris (snags, down logs), litter, and in the soil.^{439, 440, 441, 442}

Old forests store much more carbon in living matter, standing and downed wood, and in the soil, than do younger forests.^{443, 444} The Carbon Budget Model for Canada's Forests (1999) estimates that B.C.'s Pacific Maritime and Montane Cordillera ecozones store on average about 350 tonnes of carbon per hectare.⁴⁴⁵ Individual forest ecosystems in these ecozones can store considerably more than the average, from 600 to 1300 tonnes of carbon per hectare.^{446, 447}

The conversion of mature or old forests to young forests, whether through logging or natural stand-replacing disturbances, results in a pulse of carbon release immediately and for several years thereafter. This is because a) a lot of tree carbon is lost immediately after logging or fire; and b) disturbance to the soil and the original vegetation, and sometimes warming of the site, results in an increased rate of decomposition of coarse woody debris, litter, and soil organic matter, whereby losses of CO₂ due to respiration exceed the amount fixed through photosynthesis by the regenerating forest.⁴⁴⁸ Moreover, in industrially managed forests, the overall carbon store is reduced if the secondary forest is managed on typical commercial rotations. For example, logging old-growth spruce forests in central B.C. and converting them to industrially managed forests reduced total carbon storage (initially 324 to 423 t C/ha) by 41 to 54 percent.⁴⁴⁹

A Pacific Northwest study⁴⁵⁰ found that:

- total carbon storage in a 450-year old Douglas-fir—western hemlock forest was more than twice that in a 60-year old plantation;
- conversion of a typical Pacific Northwest old-growth forest to a young secondary (post-logging) forest reduces carbon storage by 305 t C/ha during one 60-year rotation, even when off-site storage of carbon in wood products is included; and
- the harvest of old-growth forests reduced total carbon storage for at least 250 years.

“... old-growth forests are usually carbon sinks. Because old-growth forests steadily accumulate carbon for centuries, they contain vast quantities of it. They will lose much of this carbon to the atmosphere if they are disturbed, so carbon-accounting rules for forests should give credit for leaving old-growth forest intact.”⁴⁵¹

2.5.2 A Standing Tree or Wood Products?

Carbon dynamics of old versus young forests are sensitive to other factors: proportion of felled wood that becomes wood products in long-term storage (for example, buildings), rotation length, and ‘permanence’ (longevity of storage). Secondary forests could recapture the lost forest carbon if harvest rotations were sufficiently long to permit full recovery of carbon stocks. But conventional short rotations and relatively short ‘life cycle’ of wood products result in significant one-time net losses:

- The research on wood products indicates that half-lives range from between one and three years for paper and between 30 and 50 years for sawn wood,⁴⁵² not several hundred years as some claim. Wood products often end up in landfills, where their carbon could be ‘stored’ if the wood isn’t incinerated.

However, wood also has the potential to decompose in landfills probably more rapidly than in cool acidic natural forest floors, and to increase emissions of methane.

- Different assumptions have been made as to how much carbon from the logged forest is transferred to wood products. In the interior, it is estimated that although 70 percent of the wood makes it to the mill, only half of that makes it into longer-lived wood products with the rest ending up as short-lived chips, sawdust and hog fuel.⁴⁵³
- In some cool wet B.C. forests where there is lots of decay and cull wood (such as the outer coast or upper Nass Valley), it has been common practice to log old growth, retrieve less than 15 percent of the volume as saw logs, and in the absence of a pulp mill or favourable pulp market, push the rest of the trees into huge piles and burn them.
- The considerable surface area of logging roads and landings represents a mostly permanent loss of carbon storage potential, and typically hasn't been factored into carbon accounting.
- Similarly, the emissions from the machinery of industrial forestry—harvesting, processing, transport, manufacture and delivery—are rarely factored into carbon accounting.

Another argument is that, over time, long-lasting wood products could be substituted for fossil-fuel-intensive products like concrete, steel, and aluminium. Even though carbon storage in wood products will always be less than in an undisturbed forest (because of inherent inefficiencies in converting trees to wood products), this strategy has some validity if indeed wood is substituted for other construction materials.⁴⁵⁴ However, in the present policy and regulatory environment, there is no guarantee that such substitution would occur, and no way to quantify it.

In the current California Climate Action Reserve (CAR, formerly the California Climate Action Registry) Forest Project Protocols version 3.0,⁴⁵⁵ the product-substitution scenario must satisfy the criteria for any other carbon-offset program—namely, baseline, additionality, leakage, and permanence.⁴⁵⁶ The CAR methods (now being adapted as the protocol for North American standards) for accounting for long-term storage of wood products are adapted from a review paper for different US forest types.⁴⁵⁷ It is worth quoting directly from this state-of-the-art protocol to highlight the research gaps in data for full carbon accounting.

“Because of the significant uncertainties associated with predicting wood product carbon storage over 100 years, the accounting requirements in this appendix are designed to err on the side of conservativeness. This means the calculations are designed to reduce the risk of overestimating the GHG reductions and removals achieved by a Forest Project. One of the largest sources of uncertainty is predicting the amount of wood product carbon likely to be stored in landfills.”

The presumed benefits of substitution could also be over-stated in that they are cumulative and would exceed the carbon storage of an unlogged forest only after several decades. Over subsequent rotations an industrially managed forest could be carbon-neutral. But the benefits of carbon storage by intact natural forests are immediate and greater than anticipated storage (more accurately, avoided emissions) in wood products in the future. The imperative is to avoid carbon emissions now, not hope for increased sequestration rates 40 years from now.

The agroforestry + wood products strategy also assumes that old forests exhibit little or no increase in carbon storage, which as discussed above is an incorrect assumption in some forest types. Proponents of this strategy also typically assume that initial stores of carbon are zero, which is not the case in B.C. production forestry because it is practiced on previously naturally forested land. If a forest stand originates from logging a mature or old-growth forest, and is managed intensively on a short rotation, it may never attain the original levels of carbon storage—in effect incurring a permanent ‘carbon debt’.⁴⁵⁸

Intensive forest management typically draws carbon stores down by increasing the frequency and intensity of disturbance, thereby reducing amounts of coarse woody debris, resulting in lower levels of dead carbon storage—to say nothing of negative impacts on forest biodiversity.^{459, 460, 461, 462, 463} The consensus of scientific

opinion appears to be that logging old forests for wood products and converting the primary forests into industrially managed forests, especially production plantations, releases large and essentially unrecoverable amounts of carbon to the atmosphere, and that landscapes dominated by mature and older forests can store several times as much carbon as intensively managed, industrial forest landscapes.^{464, 465, 466, 467, 468}

2.5.3 Are Forests Sinks or Sources?

The case for forests as carbon sinks has been complicated by the issue of **permanence**.⁴⁶⁹ Is climate change affecting the carbon balance sheet? There is evidence that climate change is resulting in increased release of carbon in some forests into the atmosphere, flipping them from being carbon sinks to carbon sources, with increased releases attributed primarily to increased fire and insect outbreaks.^{470, 471, 472, 473} These results have largely been determined from standard national forest inventory of above-ground tree stems at the national or biome level. The suitability of estimating total carbon stocks from these sources has been questioned.^{474, 475} Currently, there is scientific consensus that carbon sequestration and storage need to be evaluated using a wider range of carbon pools (including the below ground pool), and that regional variations are critical and must be included in carbon accounting.^{476, 477} The emerging methods of measuring carbon in all pools and for different ecosystems are now enabling more accurate estimates of carbon stored in our diverse forest ecosystems.



Increased conservation of forests makes economic sense. Photo Linda Mirro

Coastal and interior rainforests, southern montane forests

There is consensus that temperate rainforests (coastal and interior) and southern montane forests, which have faster-growing and bigger trees, sequester and store more carbon per hectare than slower growing, northern forests.⁴⁷⁸ Some forests in B.C. carry on functionally intact for centuries, thus developing very large, long-term carbon pools. Forest longevity depends on the disturbance regime that prevails in the region or ecological zone in which the forest occurs. If stand-replacing disturbances are rare, as they are in wet coastal forests,⁴⁷⁹ many wet subalpine forests,⁴⁸⁰ and some interior wet-belt forests, older forests will occupy the majority of the landscape⁴⁸¹ and they will continue to be net carbon sinks. As discussed earlier, there is evidence that some Oregon and northern California forests continue to have positive net ecosystem productivity even after 800 years.⁴⁸² Extrapolating to this province suggests that comparable B.C. forests with lower temperatures and more moisture availability will be equally if not more productive carbon sinks.

Interior dry forests

In interior forests with more active disturbance regimes, the forests don't get as old but they still continue to store carbon. Carbon stocks continue to accumulate in multi-aged, mixed species stands because the respiration rates of the trunks of trees decrease with increasing tree size, and the constant renewal of leaves, roots and debris builds organic soil stability.⁴⁸³ Given sufficient time, forests attacked by insect outbreaks could again become carbon sinks, although climate warming and increased fire frequency make this uncertain.^{484, 485, 486} There is also some relationship between insect outbreaks and fire risk and hazard,⁴⁸⁷ but large catastrophic fire does not automatically follow on the heels of an insect epidemic.^{488, 489, 490} A recent Colorado study finds no compelling evidence that, once the dead needles have fallen from the trees (that is, when the 'red phase' disappears a few years after attack), dead stands of pine are more likely than live stands to burn. Fire hazard depends on the type of fuels available—especially flammable are the fine fuels (dead needles, twigs) that are abundant only in the early aftermath of an epidemic—and of course on weather conditions.⁴⁹¹



Natural ecosystems play a key role in mitigating climate change. Not only as a reservoir for carbon but also as a source of biodiversity.

Photo Robert Blanchard

Another dynamic in the permanence argument is potential increasing carbon uptake by forests as CO₂ levels rise. There is growing evidence that natural forests, both tropical and temperate, are sequestering more CO₂ than previously realised, increasing their capacity as sinks.^{492, 493} Natural forests will continue to sequester and store carbon for as long as there is adequate water and solar radiation for photosynthesis.

As the genetic and taxonomic composition of our forests changes, modelling continues to be done on their carbon balances. Existing trends indicate rising rates of tree mortality—at least in B.C.'s southern forests.⁴⁹⁴ Previous models simply evaluated carbon in standing timber. Improved models will incorporate broader carbon pools (including soils), increased carbon uptake, and differential rates of tree mortality for different ecoregions, enabling more accurate carbon accounting. Such work will help clarify the sink /source issue.⁴⁹⁵

Even with increased insect outbreaks and subsequent fires, these natural disturbances still have less impact per hectare on carbon emissions than conventional forest management. When a forest burns, the majority of its biomass remains on site, where it subsequently decays and slowly releases carbon. Logging removes 50 to 80 percent of a forest's total above-ground biomass, only some of which ends up in wood products.⁴⁹⁶ Some logged forests are also destumped to mitigate root disease, which greatly accelerates decomposition of soil, organic carbon and stumps.⁴⁹⁷ Forest fires, although variable, consume much less, perhaps 5 to 15 percent of above-ground woody biomass.⁴⁹⁸ Fire rarely entirely burns large landscapes.⁴⁹⁹

Also regardless of increasing mortality, the protection of these forests offers immediate net carbon benefits. Stored carbon has much greater time value now than future anticipated carbon some decades hence. This is

a key point that requires emphasis and repetition. Keeping forests buys us time to develop alternative energy strategies to reduce CO₂ emissions, to change our behaviour, and also to establish a lower GHG base level, thus reducing the ultimate impact from warming on the forests themselves.

Northern forests

Different dynamics could come into play in our northern forests. As climate warms and forest fire intensity increases, regeneration of deciduous trees could be favoured over that of conifers. Deciduous forests do not burn easily, indeed they can function as firebreaks. Conversion of evergreen coniferous to broadleaf deciduous forest has two negative (stabilising) feedbacks to subsequent fire risk:

- The addition of a deciduous forest stage reduces landscape flammability by adding several decades—about 50 years—to the low-flammability phase of boreal forest succession.⁵⁰⁰ This conversion tends to reduce the magnitude of warming-induced increases in fire extent.
- Wildfires release CO₂ through combustion and heightened decomposition in warmer postfire soils. But postfire deciduous forests absorb and transfer less heat to the atmosphere than do late-successional spruce stands, thus an increase in deciduous forest results in a local cooling effect, to some extent counteracting the warming effect of more atmospheric CO₂.

Some research suggests that allowing northern wildfires to burn in areas where the risk to human communities is small could provide global and regional benefits by reducing the high-latitude amplification of global warming. And the reduced landscape flammability in areas where fires already burn extensively could be a positive outcome, helping the fire regime adjust naturally to a warming climate.⁵⁰¹ Other research suggests large positive (destabilising) feedbacks to atmospheric carbon because of the warming of the permafrost.⁵⁰² Of course there could also be undesirable consequences for local human communities, in terms of changes in wildlife and other subsistence resources after wildfire. Woodland caribou, marten, wolverine and other forest carnivores in particular could also be negatively affected.⁵⁰³

2.5.4 Bioenergy: Substitution or Source?

One of the economic opportunities identified for central B.C. forests attacked by the mountain pine beetle is a bioenergy industry from dead wood. The carbon debate for and against bioenergy, again, largely gets mired in incomplete data on full cost carbon accounting for different scenarios. A complete cost/benefit analysis would have to factor in carbon emissions from obtaining the wood, from disturbing the soil and from burning the wood, and would require the ability to track substitution calculations from cradle to grave for comparison and to clearly demonstrate that leakage is not occurring.

The general case for mitigating emissions from fossil fuels by using bioenergy (in particular ethanol) instead of hydrocarbons is that the energy generated from dead wood would substitute for an equivalent amount of energy generated from fossil carbon in hydrocarbons. But on that reasoning alone, wood is a difficult substitute, unless as a byproduct, because typically it has one-third to one-quarter the energy intensity, for example, BTU/lb, of fossil fuels. This means that more CO₂ has to be put into the atmosphere with wood, compared with fossil fuels, to get a unit of energy. Energy costs (and therefore emissions) to retrieve wood are very high and that is why all current energy-generating facilities from wood waste are at the site of sawmills or residue piles, where the cost of wood retrieval has already been covered by the lumber or other products.⁵⁰⁴

Another key piece of the bioenergy issue is around time frames for reaching carbon neutrality. In fact, bioenergy is not carbon neutral, but rather contributes carbon to the atmosphere, which will take several decades to recover. In addition to the CO₂ emissions from combustion of woody biomass to produce energy, carbon losses start at harvest. Beyond the immediate removal of the trees, recent studies in BC's primary

sub-boreal forests reveal that clearcutting decreases carbon stocks by approximately 100 tonnes per hectare, in addition to carbon emissions from soil disturbance.⁵⁰⁵ This happens because below-ground respiration exceeds photosynthesis, contributing to an overall net increase in CO₂ emissions of 33 tonnes per hectare over 8 years, despite the 1-1.2 tonnes carbon sequestered per hectare by growing seedlings.⁵⁰⁶ In other words, clearcutting these BC forests not only results in significant and immediate carbon emissions, but also makes them net carbon sources for 8 to 10 years after logging.

From the ecosystem services perspective, there are several key elements to the bioenergy discussion. Although many of the canopy trees are dead, the forest is still alive, it still functions as a forest, and many forest species can survive and thrive in a beetle-“killed” forest. Soil is still undisturbed with intact carbon pools. The standing deadwood persists for a long time, especially in the cold dry climates of interior B.C., releasing carbon very slowly while a secondary forest grows up. Post-beetle wildfire is not a given, nor can the location and severity of fires be predicted.

Bioenergy might be defensible as a secondary by-product industry, where there is waste from an existing processing facility, such as with a sawmill. However, aside from the fact that bioenergy would have immediate net negative carbon impacts, even when sourced from the 15-20-year supply of beetle-killed trees, as a primary industry with a continual demand for fibre, additional pressure may fall on natural forests, resulting in loss of ecosystem services and adaptive capacity. A better policy choice would be to reduce energy consumption and increase its efficiency, conserve existing natural forests, and put the emphasis on restoring disturbed or degraded forests.⁵⁰⁷ Some of the recent work on determining gross ecosystem production through satellite imagery might provide key and accurate data into changing carbon balances in the pine beetle forests.⁵⁰⁸

2.5.5 Summary of Emerging Research into Forest/Carbon Dynamics

Natural ecosystems play a key role in mitigating climate change. In B.C., forests and their soils are the chief reservoir of living and dead carbon, and thus are a linchpin of carbon dynamics. In summary:

- Protecting forests provide immediate net carbon benefits. Currently stored carbon has much greater value to the atmosphere than future anticipated carbon some decades hence. Given that the conservative Intergovernmental Panel on Climate Change target is to reduce carbon emissions 80 percent to 95 percent below 1990 levels by 2050, the imperative is to avoid needless release of any additional carbon currently stored in trees or soils.
- When old forests are logged and their soils disturbed, they release carbon to the atmosphere immediately, and continue to do so for decades and sometimes for over a century.
- Logging results not only in losses to above- and below-ground carbon stocks, but also in lower rates of sequestration for three to four decades, until rates of net carbon uptake in the secondary forest return to pre-harvest rates.
- Industrially managed forests store less carbon than natural forests. Carbon stock recovery takes decades and even centuries, and managed forests may never attain original carbon storage levels if they continue to be logged and replanted on short commercial rotations.
- Regardless of whether some types of B.C. forests are a net source or a sink at any given moment, they continue to store tonnes of carbon as long as the trees remain, even if they are dead.
- Intact peatlands, northern permafrost ecosystems, grasslands and alplands in the terrestrial realm, and oceans, all have roles to play in carbon sequestration and storage and should be part of a climate change mitigation strategy.

The consensus of scientific opinion appears to be that clearcut logging old-growth forests for wood products and converting the primary forests into industrially managed forests, especially plantations, releases large and not fully recoverable amounts of carbon to the atmosphere. This release over time is most significant for

ecosystems where large natural disturbances are relatively rare—including coastal and interior temperate rainforests, wet montane and subalpine forests, plus smaller scale areas within drier landscapes where disturbances are naturally rare.

Ecosystems with higher disturbance frequencies will also continue to store tonnes of carbon, and their stored carbon has much greater value for mitigating emissions now than does anticipated post-reforestation storage decades from now. Certain scenarios, using bioenergy and wood products as secondary by-products, might offer a net carbon gain through the substitution for fossil fuels, but near-term carbon storage in standing forests (even with canopy dieoff) is invaluable.

Infrequently disturbed landscapes dominated by mature and older forests and their soils can store several times as much carbon as intensively managed, industrial forest landscapes. In terms of carbon stewardship, moving further towards an agro-industrial approach to forest management (as is proposed by the current provincial government) is a losing proposition.

From a global perspective, the use of wood products can have lower GHG implications than the use of many other products, for example, steel or concrete. However, in the present policy and regulatory environment, there are insufficient guarantees that substitution of wood for more manufactured materials will occur. Rather than increasing the volume of low-quality products, a focus on higher quality, more expensive, and therefore less expendable wood products will provide greater benefits for long-term carbon storage. Overall, the benefits of carbon storage by intact natural forests are immediate and greater than anticipated storage (or more accurately, avoided emissions) in wood products in the future.

2.6 Current Forest/Carbon Mitigation Pilots

“Carbon management is moving rapidly from concept to practice in virtually all sectors of the economy. This simultaneously creates new challenges and new opportunities. Although the science is reasonably well understood, the implications for forest operations in British Columbia are still largely unknown among forest managers.”⁵⁰⁹

There is a growing recognition that the market for tradable carbon credits has presented a new and important measurable economic value to provide incentives for conserving forests or improving management of forests.⁵¹⁰ Experimentation with managing forests as complex adaptive systems with multiple values has led to a variety of pilot projects in B.C. Researchers are developing these pilots to assess the opportunities within different management scenarios. A recent economic study by Simon Fraser University researchers examined three different forest management scenarios in the Fraser Valley Timber Supply Area of southwestern B.C.:⁵¹¹

1. Business-as-usual—logging proceeds according to current guidelines for old-growth forests within the range of the spotted owl in B.C.;
2. Increased conservation—all forest stands that currently meet minimum requirements for suitable spotted owl habitat are preserved or removed from the timber harvesting land base;
3. Increased plus expanded conservation—protection of forests currently suitable for spotted owls plus adjacent logged areas that with time will develop into suitable owl habitat.

For each scenario and for three different sets of log price assumptions, the researchers calculated the economic values for timber, recreational use of forests, non-timber forest products, and carbon storage. The results indicate that, in 72 of 81 different projections, increased conservation makes better economic sense than does business-as-usual.

“...there would be a net benefit rather than an opportunity cost associated with increased preservation of old-growth forests. In other words, the benefits of preservation in terms of increased recreational opportunities, non-timber forest products, and carbon sequestration and storage outweigh the costs in terms of lost producer surplus from timber harvesting.”⁵¹²

Note that the estimated values of increased conservation are conservative. The study did not factor in other valuable ecosystem services such as provision of clean water, erosion control, and flood regulation. However, the evaluations used a discount rate of 4 percent and a future price for carbon of \$75 per tonne, which currently overestimates the existing value of carbon. Also, the trade-off is not all or nothing. Both scenarios of increased conservation would continue to produce some timber: 1.07 to 0.96 million m³/yr compared to 1.43 million m³/yr for the status quo.

Various experimental management plans have been developed for forests in Chilliwack, Hope, Gulf Islands and Sunshine Coast through the University of British Columbia Forestry Department. Modelling different management scenarios, researchers found that optimal scenarios maximise carbon and ecosystem service values.⁵¹³

Actual carbon valuation is being undertaken on Darkwoods, a 55,000 hectare tract of forest in the South Selkirks, between Nelson and Creston, that has been purchased by the Nature Conservancy of Canada. Carbon pools are being valued under international compliance standards. It could well be the first forest evaluated for compliance carbon offsets in British Columbia.⁵¹⁴ Land trusts, First Nations communities, municipalities, and other land managing agencies are initiating several other pilot projects looking at opportunities for carbon management and conservation offsets.⁵¹⁵ These projects are predominantly voluntary and proprietary but point to an emerging body of professional expertise and potential projects.

Meanwhile, B.C. has been a leader in Canada with the creation of a Climate Action Plan that establishes a regulatory framework for offsetting emissions in conjunction with the Western Climate Initiative states and provinces. The first 'conservation' offsets or avoided degradation offsets (REDD-equivalent) of the Western Climate Initiative have already been registered with the California Climate Action Reserve. In California, the Garcia Forest Projects and Lompico Headwaters Forest Projects have set important precedents for the development of future emissions reduction projects based on Improved Forest Management and forest protection respectively.⁵¹⁶ Fourteen thousand carbon credits will be sold from the Lompico Forest Carbon Project by Sempervirens Fund, a land trust, to Pacific Gas and Electric as part of PG&E's ClimateSmart Program. B.C. has established its own Pacific Carbon Trust to assist the public sector in its attempt in becoming carbon neutral by 2010. Also, the B.C. government has indicated that they will be passing



A climate change mitigation strategy can help sustain the web of life, our natural capital and ecosystem services, and ecological connectivity.

Photo iStock

legislation for zero net deforestation by 2015. The Forest Protocols, developed for the California Climate Action Reserve, were used and provided a model for B.C.'s Darkwoods Forest Project which may well be the first carbon credits registered for avoided degradation and some form of carbon management in B.C.

Nationally, the Montreal Climate Exchange (MCEX), a joint venture between the Chicago Climate Exchange and the Montreal Exchange was launched in May 2008 to serve the evolving Canadian emissions markets as policy guidelines continue to develop, and the Federal Government issued a draft 'Guide for protocol developers' on August 9, 2008. At the anticipated publication date of this report, the US was still debating a cap and trade program, and its role in the December 2009 Copenhagen climate talks. Internationally, Reduced Emissions for Deforestation and Degradation (REDD) are anticipated to be implemented, and countries that ratify the protocol and qualify will be able to offset carbon emissions through projects that avoid deforestation and land degradation.⁵¹⁷

The business of offsets might well outstrip any political resistance and certainly in B.C., the markets, from a variety of different sectors, are poised to take action.⁵¹⁸ The Climate Exchange Company (the world's leading specialist exchange for trading emissions and environmental services) posted their returns for 2008 indicating a 2.6 times growth in volumes in 2008—and is still growing fast in a time of economic recession.⁵¹⁹ The international carbon trading market was valued at more than \$60 billion USD in 2008, more than double that of 2007. The international market for carbon is expected to hit \$3 trillion USD by 2020.⁵²⁰ Based on recent estimates of the global cost of carbon, the carbon stored by B.C.'s forests is worth between about \$500 to \$750 billion Canadian dollars.^{521, 522}

It is useful to quote in its entirety the introduction from Brinkman and Hebda's *Credible Conservation Offsets for Natural Areas in B.C.*⁵²³

“British Columbia specifically has much potential to be a provider and model for the provision and the incorporation of ecosystem services into a valuation program, and thus be a world leader in this realm. The province has the greatest biological diversity at ecological and taxonomic scales in the country and much of it remains in a relatively sound state (Austin et al. 2008). This makes the region an excellent place to invest in many services particularly those related to biodiversity and climate change adaptation. The region has a stable social infrastructure and governance thus strong potential for permanence. There is also well-developed professional competence to assess ecosystem values in a systematic manner. Indeed British Columbia is a world leader in measuring and understanding biological diversity and ecosystem characteristics.”

Industry, to date, has only undertaken a few forest carbon projects, looking at forest certification and trial sequestration. The situation is predicted to change very rapidly due to investors demanding accountability for carbon emissions and government requiring reporting for their accounting of carbon.⁵²⁴ Although the B.C. government has not initiated any forest carbon projects, a three year strategic plan to address ecological research, climate forecasting, ecosystem monitoring and policy evaluation has been implemented through the Future Forest Ecosystems Initiative, where carbon is identified as a key element of the ecosystem processes and ecosystem services. Policy and research are being generated on climate change issues. Meanwhile, ecosystem-based management, is being applied on the ground and expertise is developing.⁵²⁵ Although the protocols for Improved Forest Management for carbon can differ from ecosystem-based management, the two approaches are complementary and could be developed together.

2.6.1 Summary of Forest/Carbon Mitigation Pilots

The ecological services of B.C.'s forests, by way of soil and water conservation, flood control, biological legacies, biodiversity niches and buffer forests provide compelling arguments for their conservation. Modelling of different scenarios examining future values for timber, recreational use of forests, non-timber forest products, and carbon storage indicates that increased conservation of forests also makes better economic sense than business-as-usual management approaches.

Some of the first pilot forest projects in B.C. providing real data on carbon values are underway. The first sales of forest carbon credits for avoided degradation and improved forest management have occurred in California. The California forest protocols provide a model for B.C. to follow and to improve on, with regard to avoided deforestation and degradation. International standards, protocols and markets are beginning to coalesce around forest carbon projects.

Scientific knowledge of carbon dynamics and methodologies for quantifying complex fluctuations is expanding rapidly. It is now possible to assess carbon pools in different forested ecosystems with trajectories over the next 100 years, taking into account succession and disturbances. As the science emerges, the policy is also catching up to account for additionality, permanence and leakage.

To be serious about climate change mitigation, British Columbia must adopt a climate change mitigation strategy that:

- Maximizes the amount of carbon retained in the forest ecosystem—in biomass, forest litter, and in the soil;
- Prioritizes conservation of productive and long-lived coastal, interior wetbelt, montane, and subalpine forests;
- Restores forests that have been logged or that have experienced stand-replacing natural disturbances to regrow and realize their carbon sink and storage potential;
- Sustains the web of life/biodiversity, conserves natural capital, and maintains ecosystem services and connectivity;
- Develops forest/carbon offset protocols that simultaneously address biodiversity goals and objectives of reducing carbon emissions by avoiding deforestation and degradation from harvesting; and
- Takes advantage of the economic opportunities provided by carbon offset activities.



B.C. must adopt a multidimensional strategy for climate change mitigation.

Photo Henry Feather

Part 3: Priority Recommendations



Photo Jason Verschuur

1 . Integrate Nature Conservation Strategies with Climate Action Strategies

The conservation of natural ecosystems has clear and immediate benefits for adapting to and mitigating climate change, benefits that should be accorded full value and understood as dual components of a comprehensive climate action strategy. The obvious overlaps, methodologically (and perhaps spatially), between conserving carbon and conserving biodiversity lead inevitably to the conclusion of integrating biodiversity conservation with carbon mitigation and adaptation strategies.



A pika in the Rockies. Pikas are particularly sensitive to the high elevation impacts of climate change. Photo CPAWS

The two strands of this report converge in its central recommendation: **to develop a comprehensive provincial Nature Conservation and Climate Action Strategy that a) combines goals of biodiversity conservation and climate change action, and b) recognizes the fundamental role of ecosystem conservation in both ecological adaptation and mitigation.**

To strengthen the rigour, credibility and efficacy of such a strategy, discussions concerning policy initiatives must involve a variety of stakeholders and policy makers and be informed by a combined scientific and socio-economic analysis. A well-developed B.C. strategy could be a model for other jurisdictions that recognize the importance of including nature conservation as part of a comprehensive climate solution.

An obvious first question relevant to implementing a climate action strategy that focuses on biodiversity and ecosystem services (primarily carbon sequestration and storage), hinges on a rigorous evaluation of the degree of spatial overlap, in terms of priority areas, between the two goals. Geographic areas that are priorities for both the biodiversity survival strategy and the carbon mitigation strategy must be identified immediately before opportunities are further foreclosed. Undertaking this technical analysis will require new mapping decision-tools, including enduring features analysis, and a new mindset in terms of evaluating ecosystem services.

We must act immediately, to both avoid emissions and slow the rate of ecosystem degradation. The following key priority actions could immediately set in motion a comprehensive nature conservation and climate action strategy.

2. Broaden Core Protected Areas into a Climate Conservation Network

Fourteen protected area complexes in B.C. already each cover more than 250,000 ha and these should form the basis for an expanded conservation network, which should aim for the scientifically credible maximum. **Minimum** targets should be at least an additional 35 percent of the land base managed for biodiversity and carbon, complementing our existing parks and protected areas that cover almost 15 percent of B.C.—raising the total area of an interconnected climate conservation network to 50 percent or beyond. With mapping decision-tools that identify overlapping priority areas for conserving biodiversity and persistent carbon storage and sequestration, core conservation areas should be expanded and connected to maximize biodiversity and carbon opportunities.

New land designations and/or tenures will likely be required to guide management of the expanded conservation network that falls outside of existing protected areas. The new conservation areas should be designated primarily for biodiversity and ecosystem services, particularly that of carbon storage and sequestration. Industrial activities that would reduce the resilience or carbon stocks of these areas should not be permitted. However, a variety of activities might continue within these areas, as long as they are compatible with the long-term objectives of biodiversity conservation and adaptation, and with maximizing carbon uptake and storage.

Connectivity across the province's borders will also be key. Transboundary connectivity and corridors for migration and ecological transport should address:

- latitudinal movements—north from the U.S. (Washington, Oregon, Idaho and Montana) to B.C., and from B.C. to Yukon, Northwest Territories, and Alaska;
- longitudinal movements—east from Southeast Alaska to B.C., and from B.C. to Alberta and the northern Great Plains;
- transboundary rivers such as the Stikine, Taku, Alsek-Tatshenshini, Yukon, Liard, Peace, Columbia, Flathead, Okanagan; and



Connectivity between political regions and ecosystems will aid species in broad landscape movements—longitudinal, latitudinal and altitudinal. Photo (above) David Lewis, (left) Johnny Mikes

- physiographic lineaments or between-mountain corridors such as the Rocky-Columbia-Mackenzie Mountains, Cascade-Coast Mountains, Rocky Mountain-Tintina Trenches, Pacific coastal trough (Puget Sound-Georgia Basin-Hecate Depression-Alexander Depression).

Altitudinal movements upslope within mountain ranges should also be considered.

Work underway by organizations such as the Yellowstone to Yukon Conservation Initiative seeks to link a network of protected areas embedded in a matrix of compatible land uses. Existing large protected area complexes include:



Bighorn sheep in the Chilcotin Ark. *Photo Paul Tessier*

1. Tatshenshini-Alsek
2. Atlin-Taku (in process)
3. Stikine
4. Muskwa-Kechika
5. Haida Gwaii
6. Great Bear Rainforest
7. Strathcona-Clayoquot
8. Chilcotin Ark
9. Garibaldi-Stein
10. Cascades/Okanagan
11. Wells Gray-Cariboo Mountains
12. Central Rockies
13. Purcell-Selkirk
14. Crown of the Continent.

3. Introduce New Tools, Legislation and Incentives

There are strategies already in place, initiated by various sectors, including ecosystem-based management (EBM), voluntary stewardship and ‘best practices’ for industrial activities (for example, Forest Stewardship Council certification of logging tenures) that could address both biodiversity and carbon benefits. These initiatives should be supported and strengthened.

However, more legislation is required to give ecosystems, species, and ultimately ourselves the best chances of survival across the landscape. The integration of nature conservation and climate action strategies requires a new way of structuring our laws and land tenure system. A full review of legal reform should be a top priority.



Clayoquot Sound.

Photo David Elfstrom

In the interim, these priorities are recommended:

1. Enable new and existing mechanisms for land use decision-making to identify and establish areas for climate change purposes—that is, creating interconnected core conservation networks.
2. Create new land designations and/or tenures that recognize areas conserved for carbon stewardship, and clarify rights and responsibilities associated with these areas, particularly the rights of First Nations.
3. Fast-track amendments to draft protocols and standards to enable forest conservation and ecological restoration initiatives/projects under B.C.'s Emission Offsets Regulation, accompanied by financial incentives to ease the transition.
4. Enact legislation to protect ecosystems and species at risk.
5. Create incentives for protecting key habitat via private land stewardship, including support for conservation offsets.
6. Require consideration of climate change in environmental assessment laws, including impacts on resilience, biodiversity and ecosystem services.
7. Reform laws and policies to remove barriers to biodiversity conservation and enable ecosystem-based management.

These reforms should be accompanied by sharing of information with communities about climate change, biodiversity, and human well-being as well as strategies for management, ecosystem valuation and new business opportunities in ecological restoration and carbon stewardship. Engaging communities that are currently stressed not only by economic downturns in the resource industries, but also by some of the impacts (such as wildfire and flooding) of climate change itself, with a different vision of the landscape, might be key to economic revitalization and community restoration.

4. Provide Incentives for Stewardship in Every Sector

A conservation network needs to be complemented by supportive, nurturing matrix lands (that is, lands outside of protected areas, buffers and connecting corridors), in which human uses are sustainable, and carbon storage/sequestration and biodiversity conservation are maximised. Legal and financial incentives and tools to steward carbon and nature should be expanded to enable sustainable livelihoods across all communities, including First Nations, rural regions, community forest groups, landowners, land trusts, tenure holders and local governments, and must be respectful of First Nations land rights. People should be supported in initiatives for improved carbon/biodiversity management practices in all areas—forestry, agriculture, energy, recreation, and private land stewardship or conservation.

5. Take the Lead on Carbon/Biodiversity Valuation

British Columbia is well-positioned at the institutional, legal, social, ecological and economic levels to take advantage of the emerging economy of natural carbon sequestration. B.C. has become a leader in Canada with the creation of a Climate Action Plan that establishes a regulatory framework for offsets, in conjunction with the Western Climate Initiative states and provinces. The business of carbon and ecosystem services is expanding over the full spectrum of carbon activities from reforestation and ecological restoration to avoided degradation/deforestation. Other forest carbon activities like Improved Forest Management could provide



Subalpine forest in the Rockies. Photo Cory Johnson

other ways to manage existing industrial forests for carbon, biodiversity and wood products. Opportunities are arising regionally and internationally through the California Climate Action Reserve and potentially the Pacific Carbon Trust.

The mechanism for developing carbon stewardship projects is in its infancy in British Columbia (although B.C. companies have been doing it overseas for years) and offers a huge opportunity. The protocols and standards we create must take advantage of our homegrown expertise and our world class legacy of ecological resources. Industry, land managers, First Nations, ENGOs and government need to align behind a common broad global vision, as it is only within the global context that BC/regional forest carbon offset initiatives/projects will trade to their highest value. In terms of reduced emissions, protection of biodiversity, and generation of income, B.C. should be aiming at the highest standards both in legal reform and the international market for carbon/conservation credits. We have the opportunity and expertise to develop forest projects that command the highest prices and ensure best management practices for biodiversity conservation and adaptation. With high values, there are more opportunities for funding mechanisms. This could help alleviate the transition from a resource economy, based on exporting carbon to global markets in the form of wood, to a more diversified economy, based on absorbing and storing atmospheric carbon from the global commons.



Humans are part of nature, our survival is dependent on a healthy, functioning planet.

Photo Jim Pojar

6. Establish the Principle that Humans are Part of Nature and our Survival is Intertwined with Nature's Survival.

Confronted with the extreme threat of climate change, society must recognize that our survival is dependent on the survival of nature and that we who are pre-eminently part of nature will determine its fate. The Secretariat of the Convention on Biological Diversity (CBD) has concluded that the capacity of forests to resist change, or recover following disturbance, is dependent on biodiversity at all scales. The findings demand global implementation of strategies that integrate carbon and nature, because the resilience and stability of natural ecosystems are linked to the permanence of carbon stocks. British Columbia and its globally significant ecosystems should be leading the way.

Conclusion

The need to act now in response to rapid global climatic change is escalating. There is already ample evidence that the climate is warming, that the impacts in British Columbia will continue to be significant, and that survival of many of the province's species is at risk. While policy debates to date have concentrated on the enormous task of reducing greenhouse gases from energy sources, we must now expand the focus to include the role of nature and its ability both to enable adaptive responses and to mitigate greenhouse gas emissions. This report reviews the relevant science and offers clear recommendations for bold action by the B.C. government—to develop and implement a science-based nature conservation and climate action strategy..

Appendix: Glossary

Adaptation – (See Adaptation text box for a fuller discussion of the different definitions of this term.)

Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects.⁵²⁶ Various types of adaptation exist from highly engineered projects like the raising of dikes to protect cities to the protection of critical habitats, corridors and buffers to reduce the vulnerability of migrating wildlife.⁵²⁷

Additionality – Reduction in greenhouse gas (GHG) emissions by sources or enhancement of removals by sinks that is additional to any that would occur in the absence of the forest project or activity. To create forest carbon credits, the project originator is required to demonstrate that the reduction in carbon generated from management actions is “in addition to” what would have occurred had no change in management strategy taken place.⁵²⁸

Afforestation – The conversion of non-forested land into forest. It is the reverse of deforestation and includes areas that are actively converted from other land uses into forest through silvicultural measures.⁵²⁹

Alpha, beta and gamma diversity – Three measures of species diversity for different spatial scales. Alpha diversity refers to the diversity within a particular habitat or ecosystem, and is usually expressed as the number of species (i.e., species richness) in that ecosystem. Beta diversity refers to the total number of different species across a variety of ecosystems in a landscape. Gamma diversity is a measure of the overall regional species diversity, across different landscapes and ecosystems, and also describes the species replacements that occur over large geographic regions.

Baseline – The reference for measurable quantities from which an alternative outcome can be measured, e.g. a non-intervention scenario is used as a reference in the analysis of intervention scenarios.⁵³⁰

Biodiversity – The full variety of life, including genes, species, ecosystems, and the interactions among them.

Carbon credit – Tradable evidence of avoided greenhouse gas emissions. To generate a carbon credit, an action is taken that helps to reduce the release of CO₂ into the atmosphere, e.g., greenhouse gas pollution prevention upgrades to a production facility. The credit may be traded or sold to a facility that has been unable to reduce its emissions to allowable levels. A carbon credit is usually equivalent to one tonne of carbon dioxide equivalent (CO₂e).

Carbon offset – The act of reducing greenhouse gas emissions in one location to compensate for gases emitted in another, for example, by supporting a renewable energy project to offset emissions due to personal air travel. Carbon offsets tend to be voluntary actions.

Carbon sequestration/storage – The removal and storage of carbon from the atmosphere in carbon sinks (such as oceans, forests or soils) through physical or biological processes, such as photosynthesis. Although sequestration refers to both removal and storage, the active ‘removal’ part of the process is associated more with sequestration and for the purposes of this report, carbon storage is used to highlight that process. (Processes to store carbon mechanically are also in development, but are not the subject of this report.)

Carbon sink – An area, such as a forest, that, over a long period of time, absorbs more CO₂ than it emits.

Carbon source – An area that, over a long period of time, emits more CO₂ than it absorbs.

Climate envelope modeling – Climate envelope modeling takes existing data on spatial extent of ecological zones or species ranges, and then uses climate projections to find where these climate envelopes will exist in the future. A variety of methods are used ranging from general linear models to principal component/factor analysis.

Connectivity – The term connected or connectivity throughout this report does not refer only to linear corridors connecting two or more places. Connectivity includes ecological connections among habitats, species, communities, and processes. Connectivity enables the flow or movement of energy, nutrients, water, disturbances, and organisms and their genes at multiple spatial and temporal scales.⁵³¹

- Conservation biology* – A branch of the biological sciences that studies biodiversity, species abundance, scarcity and extinction, and the relationships of these to natural processes, habitat conditions, and population changes in response to human-induced disturbances.⁵³²
- Cryptic species* – A group of species which satisfy the biological definition of species; that is, they are reproductively isolated from each other, but their morphology is very similar (in some cases virtually identical).
- Deforestation* – The permanent conversion of forested land to another land use or the long-term reduction of tree canopy cover in a defined area to less than 10 percent. (This definition excludes forestry activities unless they result in the permanent loss of forest cover.)⁵³³
- Disturbance regimes* – Frequency, intensity, and types of disturbances, such as fires, insect or disease outbreaks, windstorms, floods, and droughts.
- Ecological restoration* – Natural regeneration of forest/other wooded land with deliberate human intervention aimed at enhancing the ability of desired species to regenerate. Interventions may include removal of external pressures, such as weeds and biotic interference; the application of controlled disturbances to trigger germination of native species such as mosaic and or ecological burns; or the preparation of the germination site e.g. through scarification. According to this definition, the source of seed or vegetative reproduction is limited to the site and its immediate surroundings.⁵³⁴ Such a limitation could be counter-productive during climate change.
- Ecosystem services* – Services provided by ecosystems that benefit humans and are necessary for a healthy planet, like oxygen production, carbon sequestration, water purification, pollination, soil formation and nutrient recycling.⁵³⁵
- Extirpation* – The elimination of a species or subspecies from a particular area, but not from its entire range.
- Facilitated migration* – (Also assisted migration). Anthropogenic translocation of species for conservation or forest productivity purposes.
- Forest degradation* – For the purposes of a harmonized set of forest definitions internationally, degradation refers to the reduction of canopy cover and/or stocking of the forest through logging, fire, wind or other events, provided that the canopy cover remains above 10% (cf. definition of deforestation).⁵³⁶ In a more general sense, forest degradation is the long-term reduction of the overall potential supply of benefits from the forest, which includes wood, biodiversity, habitat and any other product or ecosystem service.⁵³⁷ (See text B2 box on Forest Definitions).
- Foundation species* – A dominant primary producer in an ecosystem both in terms of abundance and influence.
- Genotypes* – The genetic make up of an organism, this being the sum total of all the genetic information in the organism.
- Greenhouse gases (GHG)* – Gases in the Earth’s atmosphere that absorb or emit heat. This process is the fundamental cause of the greenhouse effect. An excess of greenhouse gases leads to global warming. The main greenhouse gases in the Earth’s atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.
- Improved Forest Management* – Management practices designed to increase carbon stocks or reduce greenhouse gas emissions from forestry activities, while improving forest health and protecting biodiversity. Examples include reduced impact logging, protecting forests that might otherwise have been logged, lengthening rotation periods, and improving the stocking of poorly stocked forests (See text B2 box on Forest Definitions).⁵³⁸
- Industrially managed forest* – (See text box A2 on Forest Definitions) Those forests that are managed primarily through tree farm licences and timber supply areas. In B.C. there are a range of management activities under these tenures, from plantations to assisted natural regeneration and they vary widely in their benefits for biodiversity and carbon storage. The majority of these managed forests, however, would be considered to have experienced some form of “forest degradation” in the internationally-accepted definition of the word, through reducing biodiversity and carbon storage benefits.

- Keystone species* – A strongly interacting species whose top-down effect on species diversity and competition is large relative to its biomass dominance within a functional group.⁵³⁹
- Leakage* – The unanticipated decrease or increase in greenhouse gas (GHG) benefits outside of the carbon offset project's accounting boundary as a result of project activities.⁵⁴⁰
- Matrix lands* – Multiple use private or public lands within which protected areas are embedded.⁵⁴¹
- Managed forest* - Forest that is managed in accordance with a formal or an informal plan applied regularly over a sufficiently long period (five years or more). Different types of management practices can apply to a managed forest, from intensive fibre production to biodiversity conservation.⁵⁴² For the purposes of this report, specific descriptors of the type of management in B.C. will be referred to, e.g., industrially-managed forest. (See text box 2 on Forest Definitions below)
- Mitigation* – Practices that reduce emissions of greenhouse gases or help remove them from the atmosphere.⁵⁴³
- Natural capital* – An extension of the economic notion of capital (manufactured means of production) to environmental 'goods and services'. It refers to a stock (e.g., a forest) which produces a flow of goods (e.g., new trees, wood, animals) and services (e.g., carbon sequestration, erosion control, habitat).⁵⁴⁴
- Natural forest* – A forest composed of indigenous trees and not classified as a forest plantation.⁵⁴⁵
- Net primary production (NPP)* – A measurement of plant growth, calculated as the quantity of carbon dioxide absorbed from the atmosphere and stored as carbon by vegetation. NPP is equal to photosynthesis minus respiration and is measured in units of carbon per year.⁵⁴⁶
- Peripheral population* – Populations at the outlying limits or periphery of their natural range.
- Permanence* – Longevity of a carbon pool and the stability of its stocks within its management and disturbance environment.⁵⁴⁷
- Plantation* – Forest of introduced or native tree species, established through planting or seeding, which meet all the following criteria: one or two species at plantation, even age class, regular spacing.⁵⁴⁸
- Reforestation* – Establishment of forest plantations on temporarily unstocked forest lands.⁵⁴⁹
- Resilience* – Ecological resilience is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes **or** to absorb disturbance, undergo change and still retain essentially the same function, structure, identity and feedbacks.⁵⁵⁰

Box 1: Adaptation

Two definitions of adaptation are used in this report. The first is 'ecological' adaptation, which refers to the changes in a species so that the population is better able, from an evolutionary or physiological perspective, to survive and reproduce under a variety of conditions, thereby contributing to its fitness. This meaning is used with reference to the scientific literature on how different species are adapting to climate change. The second meaning is 'managed' adaptation, which refers to the initiatives and measures taken by humans to reduce the vulnerability of natural and human systems to actual or expected climate change effects. This is a policy definition under the IPCC for a comprehensive global climate action plan that includes mitigation and adaptation. These two strategies intersect when 'managed' adaptation strategies include conserving nature through the protection of habitat, corridors, linkages and buffers in order to improve species' chances of 'ecologically' adapting to climate change. In this report, we draw attention to the critical importance of human efforts to plan and manage for 'ecological' adaptation.

Box 2: Forest Definitions

Forest definitions have been put under huge scrutiny by the international community, because the fine details of what constitutes a ‘natural forest,’ ‘managed forest,’ ‘assisted natural regeneration forest,’ ‘plantation,’ and so on have huge repercussions for the protection of biodiversity. Offsets for ‘managed forests’ which are, in fact, monocultures will not serve nature well. For the purposes of this report, we have tried to retain the international definitions but also acknowledge that B.C. has its own history and lexicon of forest land-use. Throughout the report, the term ‘industrially managed forest’ is used. It refers to those forests that are managed primarily through tree farm licences and timber supply areas. In B.C. there are a range of management activities under these tenures, from plantations to assisted natural regeneration, and they vary widely in their benefits for biodiversity and carbon storage. The majority of these managed forests, however, would be considered to have experienced some form of ‘forest degradation’ in the internationally accepted definition of the word, through reducing biodiversity and carbon storage benefits. The corollary to ‘forest degradation’ is to practice ‘Improved Forest Management (IFM),’ which is defined as improved benefits for biodiversity and carbon. It is the hope that all industrially managed forests in British Columbia will move to an improved form of management for all ecosystem services.

Box 3: Reduced Emissions from Deforestation and Degradation (REDD)

The reduction of emissions from deforestation and forest degradation (REDD) is now recognized as a valid mechanism by the UN in the fight against climate change, targeted first at developing countries. However, regionally, the California Climate Action Reserve of the Western Climate Initiative has already started accepting REDD-type pilot forest projects (Van Eyck Forest) where the carbon stock preserved through avoiding degradation (or deforestation) is valued and accredited for carbon offsets. The experiences of forest projects already completed in the south demonstrate that the implementation of REDD at the country level will require very effective and equitable implementation strategies, tailored to each country, that facilitate evaluation, transparency and promote equity. BC has an opportunity to create the highest standard of REDD projects, especially in the area of avoided degradation, that meet international standards for mitigation and adaptation with high levels of ecological and social equity.

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