Biodiversity BC
CONSERVING THE VARIETY OF LIFE

TECHNICAL SUBCOMMITTEE COMPONENT REPORT

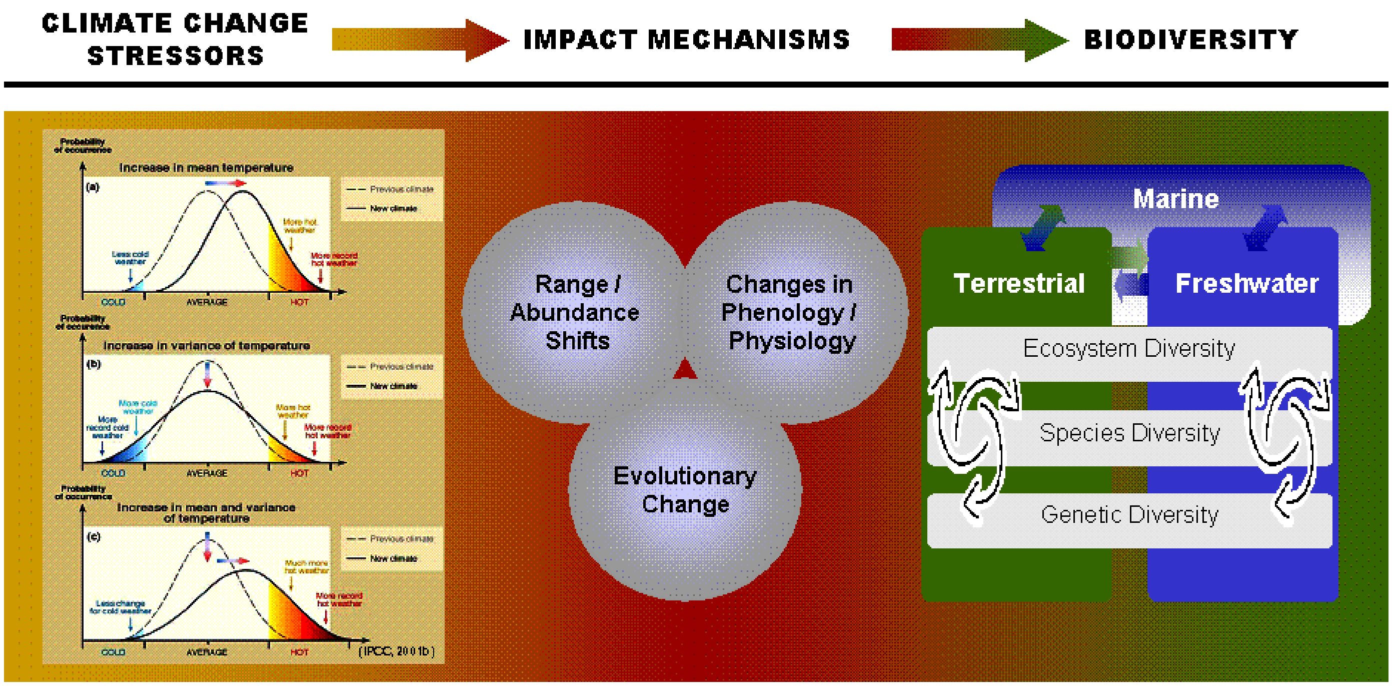
Major Impacts: Climate Change

PREPARED BY: **COMPASS RESOURCE MANAGEMENT**

FOR: **THE BIODIVERSITY BC TECHNICAL SUBCOMMITTEE FOR THE REPORT ON THE STATUS OF BIODIVERSITY IN BC**

MAY 2007

An Assessment of Climate Change Impacts on Biodiversity Management in BC



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Submitted by:

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1. Introduction

The Conservation Planning Tools Committee (CPTC), also known as the Biodiversity B.C. Steering Committee, is currently in the process of developing British Columbia's Biodiversity Action Plan. An important milestone in the development of the action plan involves the preparation of an ecological assessment that will describe the current status, impacts and trends of biodiversity in British Columbia. Climate change has been identified by the Committee as a "major impact" area worthy of detailed assessment as part of this process. Accordingly, this report provides an overall summary and assessment of climate change impacts on biodiversity management in BC.

This report has four primary sections:

> **Section 2** begins by providing a broad overview of climate change impacts on biodiversity and introducing an analytical framework that structures the assessment. Past climate trends and future climate projections for BC are then provided, followed by a compilation of current and predicted impacts.
>
> **Section 3** reviews biodiversity management in BC in the context of climate change, highlighting actions that are currently underway as well as actions that have been recommended.
>
> **Section 4** reflects on the results of the assessment, and discusses a range of management considerations that are specific to the context of biodiversity management under climate change.
>
> **Section 5** outlines broad data gaps.

This report was developed using an applied research methodology. As such, it both collates previous studies and information to date, and extrapolates toward the specific requirements of Biodiversity B.C.'s Technical Subcommittee's ecological assessment. Specific tasks undertaken include:

- Reviewing and summarizing major reports and references provided by CPTC, Government contacts, and other professional colleagues,
- Downloading climate change scenario results for BC, and synthesizing the broad trends as documented in recent government reports,
- Synthesizing and categorizing climate change impacts on biodiversity in BC and biodiversity management actions that address these impacts, and
- Identifying potential data gaps.

2. Climate Change Impacts on Biodiversity

2.1 Overview

There is growing consensus in the scientific community that climate change is occurring. Research summarized in the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report indicates that global average surface temperatures are increasing, and that snow cover and ice extent are decreasing in the higher latitudes of the Northern Hemisphere (IPCC 2001a). While the absolute magnitude of predicted changes such as these are uncertain, there is a high degree of confidence in the direction of changes, and in the recognition that climate change effects will persist for many centuries.

The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that the global atmosphere is warming, noting that the average global surface temperature has increased by nearly 1 ^{o}C over the past century and is likely to rise by another 1.4 to 5.8 ^{o}C over the next century (IPCC, 2001a). Such simple statements however mask the highly variable, site-specific and complex interactions among climate change effects. Atmospheric warming affects other aspects of the climate system: the pressure and composition of the atmosphere; the temperature of surface air, land, water, and ice; the water content of air, clouds, snow and ice; wind and ocean currents; ocean temperature, density, and salinity; and physical processes such as precipitation and evaporation.

One of the key complexities in any attempt to understand climate change in BC is to account for the natural variations and cycles that result from two major sources. The Pacific Decadal Oscillation is a natural cycling of warm and cool phases in the sea surface temperature over a 50-60 year cycle. The El Niño Southern Oscillation is a shifting of tropical air pressure patterns along the west coast over a few-year cycle. These two cycles together, coupled with BC’s complex topography and large size, make the task of predicting climate and weather in BC very complex. Despite these climate change assessment challenges and major uncertainties, certain conclusions are emerging. Of particular relevance to BC is the conclusion that climate change effects are expected to occur faster and be more pronounced than the global average over the mid and high latitudes of the Northern Hemisphere continents (IPCC, 2001a).

The potential for climate change to impact biodiversity has long been noted by the IPCC, other bodies (UNEP/IES, 1998), and by research biologists (e.g., Peters and Lovejoy, 1992). The recent leading book on the subject, *Climate Change and Biodiversity* (Lovejoy and Hannah, 2005) provides a comprehensive scientific overview of both the past and potential future effects of climate change on biodiversity, and explores the associated conservation and management challenges.

Figure 1 presents the overview analytical framework of climate change impacts on biodiversity that shape the structure of this report. In short, it involves making specific linkages along the continuum from climate change stressors to impact mechanisms and biodiversity management endpoints.

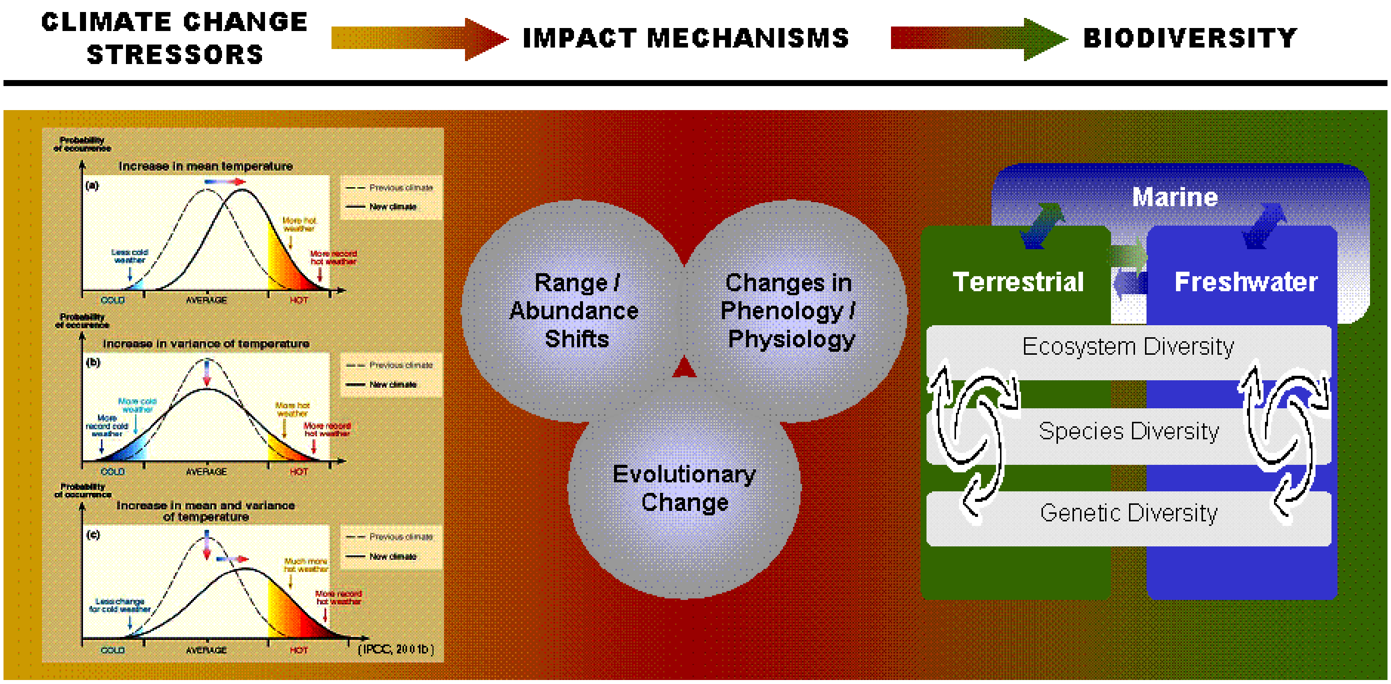


Figure 1: Overview Conceptual Framework for the Assessment of Climate Change Impacts on Biodiversity in BC

Climate change is one of many possible stressors on biodiversity. Climate change may manifest itself as a shift in mean conditions, or as changes in the variance and frequency of extremes of climatic variables (as shown in the inset figure from IPCC, 2001b in Figure 1). There is a growing recognition that planning for changes in variance and an increase in the frequency of extreme events may pose the most challenging problems for natural resource managers (IPCC 2001b).

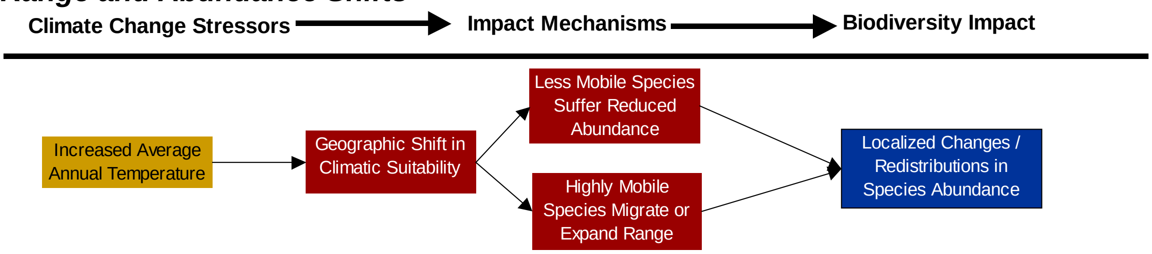
These changes in climate can impact biodiversity either directly or indirectly through many different impact mechanisms. Range and abundance shifts, changes in phenology/ physiology/behaviour, and evolutionary change are the most often cited species-level responses. At the ecosystem level, changes in structure, function, patterns of disturbance, and the increased dominance of invasive species is a noted concern. Having a clear understanding of the exact impact mechanisms is crucial from the perspective of evaluating potential management actions.

For the purposes of this report, we are structuring our assessment of biodiversity impacts using an *Ecosystems / Species / Genes* **X** *Terrestrial / Freshwater* framework. That is, we are looking for biodiversity impacts at each level of hierarchical organization, and separately within functional terrestrial and freshwater systems. At the same time we understand that there are many interactions across the levels, and between the terrestrial, freshwater and marine systems. Box 1 and box 2 provide a generic overview of some examples of frequently identified impacts in the terrestrial and freshwater realms.

Box 1: Climate Change Impacts in the Terrestrial Realm

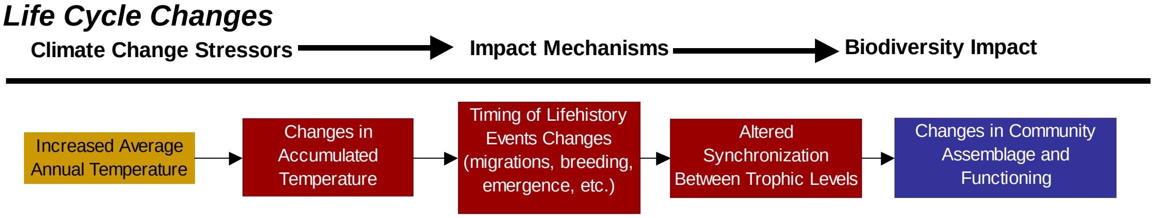
Climate change is expected to have a significant influence on terrestrial biodiversity at all system levels – ecosystem, species and genetic diversity. The changing climate will stimulate species-level changes in range and abundance, life cycle and behaviour, and, over time, genetic evolutionary responses. These changes will in turn be linked with changes in natural disturbance patterns and changes in ecosystem structure and function.

Range and Abundance Shifts



Many studies provide evidence that species have expanded their range polewards and upwards in elevation in response to climate warming (Parmesan, 2005). This has been particularly evident in the case of species that can disperse easily, such as birds and strong-flying butterflies. In a meta-analysis study covering a wide variety of more than 1700 species, more than half displayed statistically significant changes in range in the direction predicted by regional changes in climate (Parmesan and Yohe, 2003). Species that are not easily dispersed will respond more slowly to climate change, likely resulting in range contractions and reduced abundances. Ample evidence now exists that upper and lower temperature and precipitation thresholds are a strong determinant in the abundance of wild species. As the geographic range of these thresholds shifts, so too will the local abundance of many species.

Life Cycle Changes

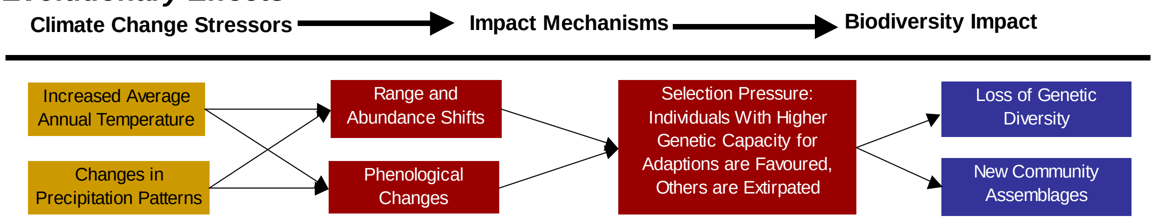


In higher latitudes, changes in phenology are expected to be the primary short-term response to climate change (Root and Hughes, 2005). The life-cycle events of many plants, insects, and animals depend on "accumulated temperature" – the amount of heat energy available over time. These organisms will hatch, bud, or breed earlier in the year in response to warming trends. Long living plants that cannot migrate will see climate change occur within their lifetimes, so their ability to undergo phenological adaptations will determine their individual survival.

In the animal world, these life cycle changes are likely to disrupt communities, potentially uncoupling predator-prey and competitive interactions between species and ultimately influencing community composition (Root and Hughes, 2005). Migratory species are particularly vulnerable since a discrepancy could develop between the timing of migration and the availability of food. Hence both the structure and functioning of ecosystems could change.

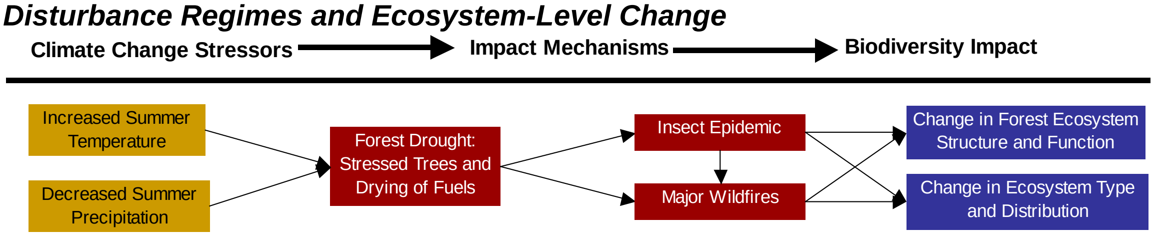
Box 1: Climate Change Impacts in the Terrestrial Realm – cont'd

Evolutionary Effects



Changes in species abundance, distribution, and phenology suggest changes in species fitness in response to climate change. Individuals within one species may have different capacities for expressing new phenotypes (e.g., hatching or budding earlier in the year) and as such, climate change might select for individuals with greater genetic capacities for these adaptations. New community assemblages and interactions resulting from climate change will also exert evolutionary pressure on species. Subpopulations at the warmer edges of species ranges are being extirpated, causing a loss in genetic diversity (Thomas, 2005).

Disturbance Regimes and Ecosystem-Level Change



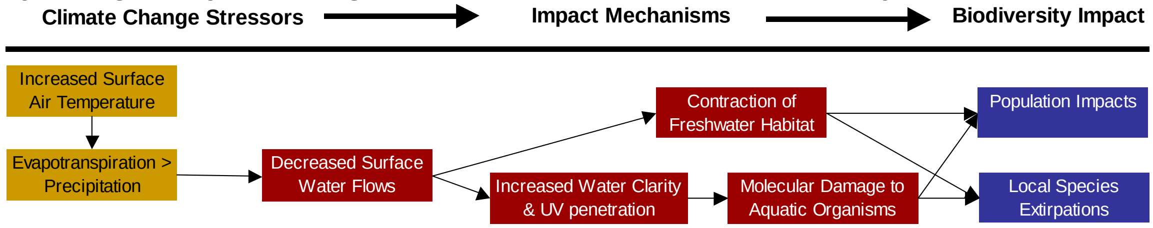
Climate change has the potential to have a profound effect on landscape-level processes, altering both the frequency and extent of major disturbance events. For example the combination of increased summer season temperatures and decreased precipitation can combine to create widespread forest ecosystem drought in boreal forest ecosystems. This in turn can lead to insect epidemics and major wildfires that can extend over vast areas with significant effects. For example, disturbance processes such as fire are the mechanism whereby some forest ecosystems may potentially be converted to grassland ecosystems. Recent research using current climate change projections indicates that both fire frequency and severity can be expected to increase significantly in boreal forests of Canada. Beyond the direct habitat loss potential, these studies conclude that the "interaction between climate and the fire regime has the potential to overshadow the direct effects of climate change on the distribution and migration of forest species" (CFS, 2006).

Changes in disturbance regimes are therefore expected to be a major driver of ecosystem-level changes that may include changes in structure (e.g., dominant vegetation, age class distribution, species composition), function (e.g., productivity, decomposition, nutrient cycling), and distribution within and across landscapes.

Box 2: Climate Change Impacts in the Freshwater Realm

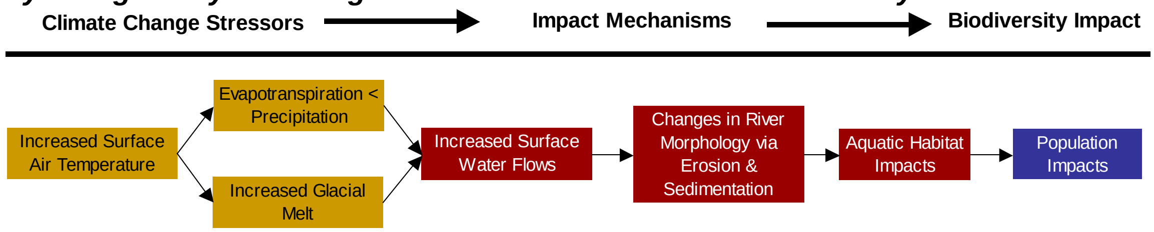
The impacts of climate change on freshwater biodiversity are highly uncertain (Allan *et al.*, 2005). With warming air temperatures, evaporation and evapotranspiration are expected to increase, as is precipitation in some areas. In essence, warming is expected to accelerate the water cycle, increasing rates at which water enters the atmosphere and rains down again. However, the impacts of this on freshwater biodiversity are uncertain since it is not clear whether evapotranspiration will be greater than, smaller than, or equal to precipitation. Given these possibilities, different impacts of these changes to the water cycle will have different consequences in different watersheds.

Hydrological Cycle Change: Reduced Surface Water Availability



In the case that summer evapotranspiration is greater than precipitation, surface water flow will be reduced in freshwater systems that are not glacier-fed. This will cause small ponds and wetlands, which are surface-water fed, to contract. A contraction in these water bodies will reduce freshwater habitat, which in turn would reduce freshwater biodiversity. Further, surface water flow is often an important source of cations for soft-water lakes. Reducing surface flow in these cases will reduce the buffering capacity of such lakes, accelerating acidification and negatively impacting organisms that cannot tolerate reductions in pH. Additionally, acidic lakes have clearer water with less protection against damaging UV rays. If surface water flow is reduced due to climate change, biodiversity losses could occur through contraction of habitat, acidification of lakes, and molecular damage associated with UV exposure.

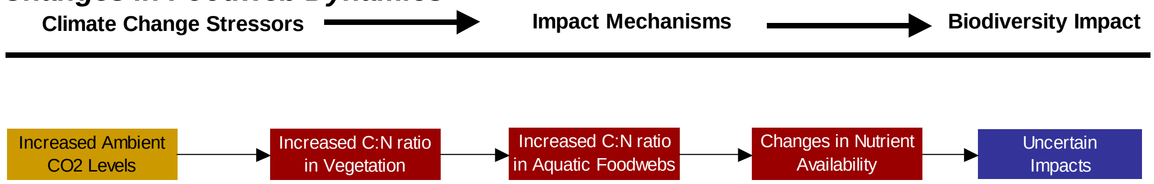
Hydrological Cycle Change: Increased Surface Water Availability



In the case that the rate of evapotranspiration is less than precipitation, water flow will increase. Increased glacial runoff due to warming will add to the increase in flow in glacier-fed systems (for a period of decades, until this runoff eventually subsides). Increased water flow could change stream channel morphology by causing erosion along the banks, and depositing sediments elsewhere. Such changes in channel morphology have direct links to freshwater species life cycle and habitat requirements (e.g., fish spawning and rearing), which in turn can have direct population-level impacts.

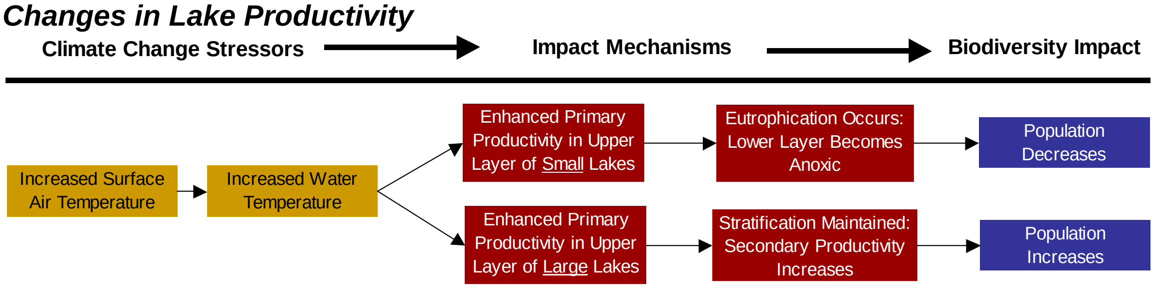
Box 2: Climate Change Impacts in the Freshwater Realm – cont'd

Changes in Foodweb Dynamics



Yet another pathway in which climate change could affect freshwater biodiversity is by altering the carbon to nitrogen ratio in riparian vegetation (Allan *et al.,* 2005). Increased ambient CO_2 generally increases the carbon to nitrogen ratio in plants. Many streams depend on leaf litter as an important nutrient input, and such streams will see a corresponding increase in carbon in their nutrient pools. This change in nutrient quality could cause corresponding changes in biological assemblages, enhancing organisms that use carbon efficiently, while suppressing those that depend on larger nitrogen inputs. Such changes in aquatic assemblages are highly uncertain, but would likely be noticeable throughout the entire foodweb.

Changes in Lake Productivity



Regardless of whether or not water flow is reduced, climate change is expected to increase the temperature of lakes and streams. In small systems, this will be detrimental to cold-water species in two ways: firstly, a direct temperature increase will reduce the survival of, and potentially extirpate species with a narrow temperature range. Secondly, in lakes, warmer temperatures will generally occur in the surface layer of the lake, and will enhance production since most aquatic organisms are cold-blooded. This increase in production can quickly lead to eutrophication in smaller lakes, in which the biological oxygen demand in the lake will increase, causing the cooler lower layer in the lake to become anoxic, potentially suffocating cool-water species. Larger lakes, however, may be able to maintain their temperature gradients despite some warming of surface layers. Such lakes may see increases in biodiversity since they are large enough to buffer the temperature effects and cool water species could actually benefit from increased production.

2.2 Focus on British Columbia

2.2.1 Past Climate Trends in British Columbia

A common starting point for assessing the potential for future climate change is to look for past climate trends. Several studies are available that formally document the magnitude and direction of climate changes that have taken place in BC.

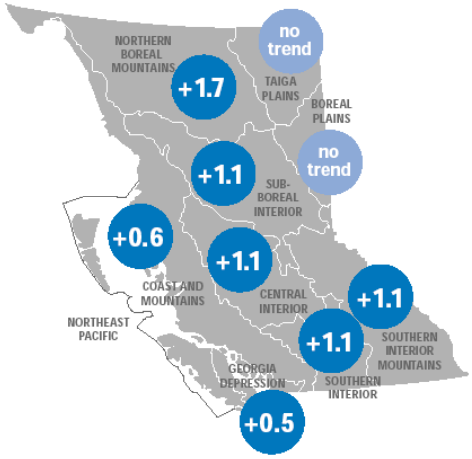
The *Indicators of Climate Change for British Columbia 2002* report (BC WLAP, 2002) documents how the climate in British Columbia changed during the 20th century using a set of indicators including primary climate change drivers (e.g., temperature, precipitation), climate system responses (e.g., sea level rise, hydrological systems) and ecosystem responses (e.g., salmon, mountain pine beetle, seabirds). Figure 2 presents an overview summary of historical changes in average annual temperature and precipitation from the report. Some of the detected changes in primary climate change drivers and climate system responses that are summarized in the report include:

Climate Change Drivers	**Biophysical Responses to Climate Change**
- Average annual temperature warmed by 0.6ºC on the coast, 1.1ºC in the interior, and 1.7ºC in northern BC. - Night-time temperatures increased across most of BC in spring and summer. - Precipitation increased in southern BC by 2 to 4 percent per decade.	- Lakes and rivers become free of ice earlier in the spring. - Sea surface temperatures increased by 0.9ºC to 1.8ºC along the BC coast. - Sea level rose by 4 to 12 centimetres along most of the BC coast. - Two large BC glaciers retreated by more than a kilometre each. - The Fraser River discharges more of its total annual flow earlier in the year. - Water in the Fraser River is warmer in summer. - More heat energy is available for plant and insect growth.

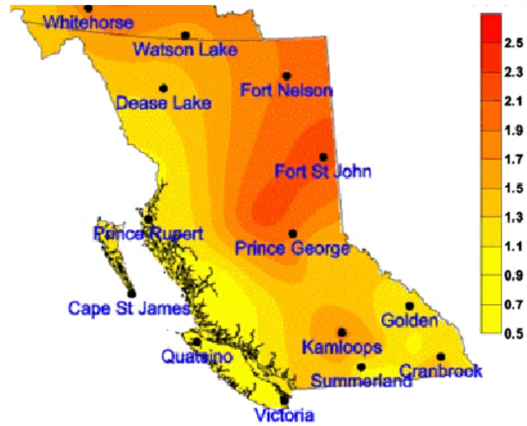
A more recent set of results using a somewhat different methodology are presented in the climate change section of the report *Alive and Inseparable: British Columbia's Coastal Environment: 2006* (BC MOE *et al.*, 2006). The report summarizes long-term trends for four indicators: air temperature, precipitation, coastal ocean temperature, and sea level. The temperature and precipitation results presented in this report use "Adjusted Historical Canadian Climate Data" provided by the Climate Research Branch of Environment Canada. The report presents results for trends in annually averaged daily minimum and daily maximum temperatures, as well as trends in annually and seasonally averaged precipitation. Figure 3 presents an overview summary of historical trends in average annual temperature and precipitation from the original data source (www.ecoinfo.ec.gc.ca/env_ind/region/climate/climate_e.cfm). Some of the detected changes in primary climate change drivers and climate system responses that are summarized in this report include:

Climate Change Drivers	**Biophysical Responses to Climate Change**
- Temperatures have been rising across the entire province, with winter and spring temperatures rising more rapidly than summer. - Total annual precipitation has increased in many parts of BC, most noticeably in the Okanagan and North Coast regions. However this masks a shift toward drier winters in most of the province. - Sea surface temperatures have been increasing along BC's coast, most noticeably at Langara Island (northwestern tip of the Queen Charlotte Islands) and at Entrance Island (central Strait of Georgia).	- A narrowing daily temperature range caused by overnight minimums increasing faster than daytime maximums has resulted in a longer growing season and more frost-free days each year. - Mean sea level rise has been detected along the coast from Victoria to Prince Rupert. There are exceptions such as in Tofino where the isostatic vertical rebound effect (from ice departure after the last ice age) cancels out the effect of an expanding ocean.

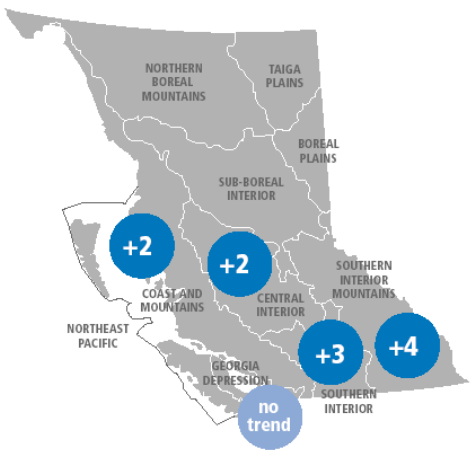
Finally, the most recent summary of past trends in BC is presented in: *Project Summary: Climate Change Index for Biodiversity* (PCIC, 2006). This report was also prepared as a background report for the Biodiversity BC Technical Subcommittee and can be obtained by contacting info@biodiversitybc.org.



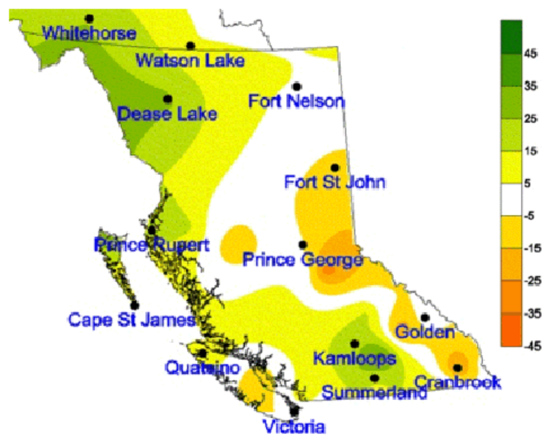
A) Change in Average Annual Temperature 1895 –1995 (°C per Century)



A) Trend in Average Annual Temperature since 1950 (°C for 52 years)



B) Change in Average Annual Precipitation 1929 –1998 (% per Decade)



B) Trend in Average Annual Precipitation since 1950 (% change from 1961-1990 average)

Figure 2: Historical change in average annual temperature (A) and precipitation (B)

Source:
BC MWLAP, 2002

Figure 3: Historical trend in average annual temperature (A) and precipitation (B)

Source:
EC, 2006: www.ecoinfo.ec.gc.ca/env_ind/region/climate/climate_e.cfm
See also: BC MOE *et al*., 2006.

Notes: 1) Maps such as in Figures 2 and 3 above are intended to show generalized trends and are not meant to represent accurate results for specific areas or locations.
2) Beyond these average annual results, there are important seasonal results. Readers are referred to the original sources listed for more detailed information.

2.2.2 Future Climate Scenarios for British Columbia

Future climate change scenarios for BC were developed from the results of a range of global circulation models (GCMs) of the atmosphere-ocean system run under a range of future GHG emission scenarios. All data and maps were extracted using tools provided by Pacific Climate Impacts Consortium (PCIC) website (http://pacificclimate.org/).

Based on advice from PCIC staff, we generated a "Low", "Medium" and "High" set of climate change scenarios for BC using three different combinations of climate models and GHG emission scenarios (see table below). This approach, which applies methods generally in accordance with the IPCC Data Distribution Center guidelines on the use of scenario data for impacts and adaptation assessments (IPCC-TGCIA, 1999), provides an opportunity for identifying both potential trends and the range of uncertainty around them.

Scenario	Global Climate Model	GHG Emission Scenario !
Low change	HadCM3: Hadley Centre for Climate Prediction and Research (UK)	B22: Intermediate levels of local economic development; slower, diverse technological change.
Medium change	CGCM2: Canadian Centre for Climate Modelling and Analysis	A22: Regionally-oriented economic development, slower; more fragmented technological change.
High change	CSIROMk2b: Commonwealth Scientific and Industrial Research Org. (Aus)	A11: Very rapid economic growth, rapid introduction of new and more efficient technologies.

! These emission scenarios are from the IPCC's Third Assessment Report (Nakicenovic et al., 2000).

The GCM results comprise 30-year monthly mean changes (i.e., no information is presented about changes in inter-annual or inter-daily variability.) All data is extracted as change values, expressed either in absolute or percentage terms, with respect to the 1961-1990 model-simulated baseline period. Results are therefore generally reported as the change between the 1961-1990 30-year mean period, and the future 30-year mean period (e.g., 2020s, 2050s or 2080s). These time periods represent 30-year mean fields centred on the decade used to name the time period, e.g., the 2020s represent the 30-year mean period 2010-2039, the 2050s represent 2040-2069 and the 2080s represent 2070-2099.

Figure 4 and Figure 5 provide maps of mean annual temperature change and mean annual precipitation change for each scenario at each future time period. By 2080, the mean annual temperature change for all of BC is shown to be in the range of +3ºC (low) to +4.8ºC (high), and the mean annual precipitation change for all of BC is shown to be in the range of 9% (low) to 18% (high). The differences across the low to high scenario results reinforces the need to explicitly recognize and account for the uncertainties that exist in projections of future climate. That said, the results are generally consistent with those reported by the IPCC for the northern hemisphere (IPCC, 2001a). There are important seasonal differences and trends that are not reflected in these annual maps. Any specific impact assessment that is sensitive to seasonal climate trends would need to generate maps and data specific to the season of interest. The PCIC website user interface provides flexibility in customizing such data requests.

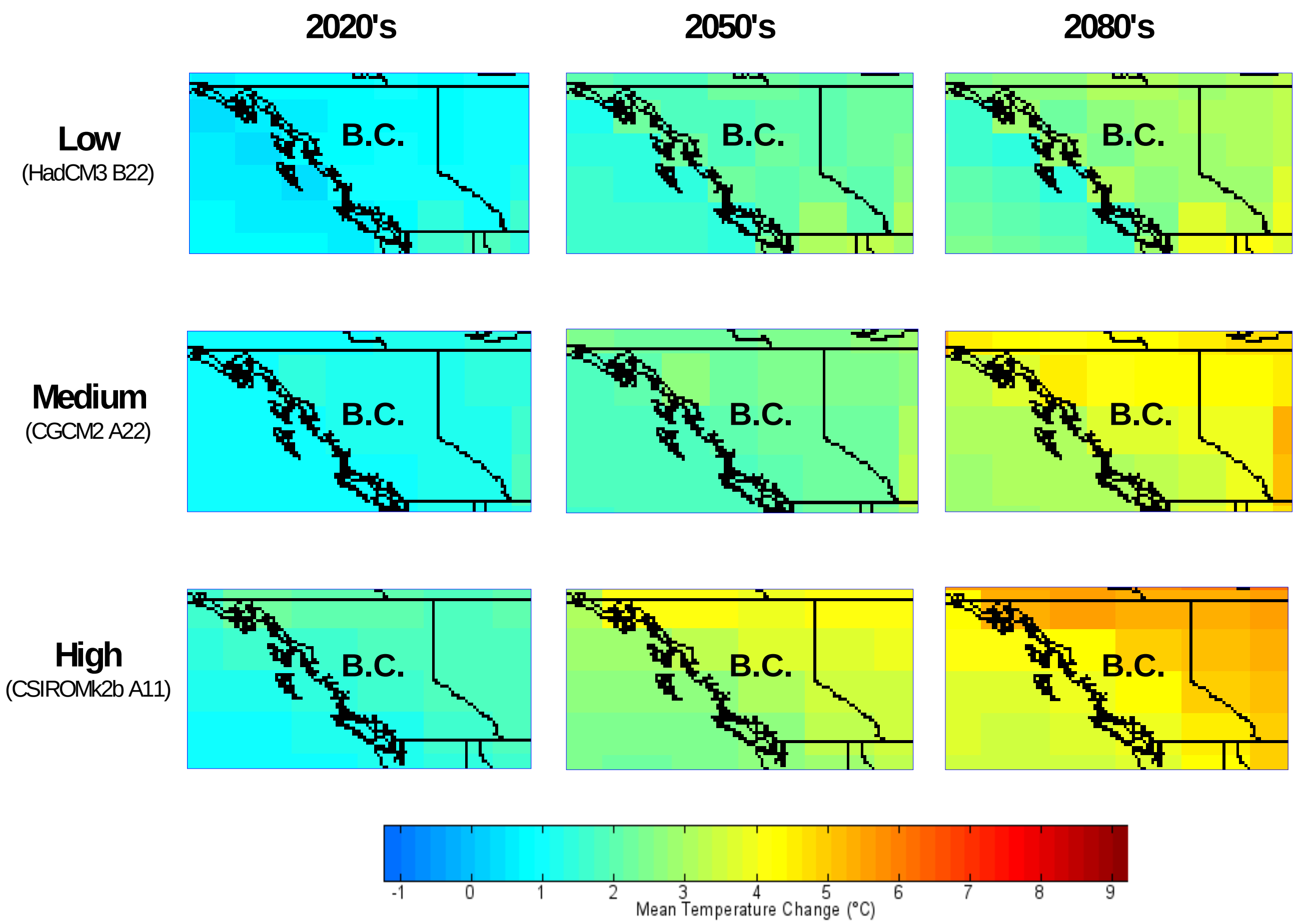


Figure 4: Summary of mean annual temperature change for 2020's, 2050's and 2080's for a low, medium and high climate change scenario. Change is relative to the 1961-1990 model-simulated baseline period.

Source:
All data and maps prepared by the Pacific Climate Impacts Consortium; downloaded from http://www.pacificclimate.org/

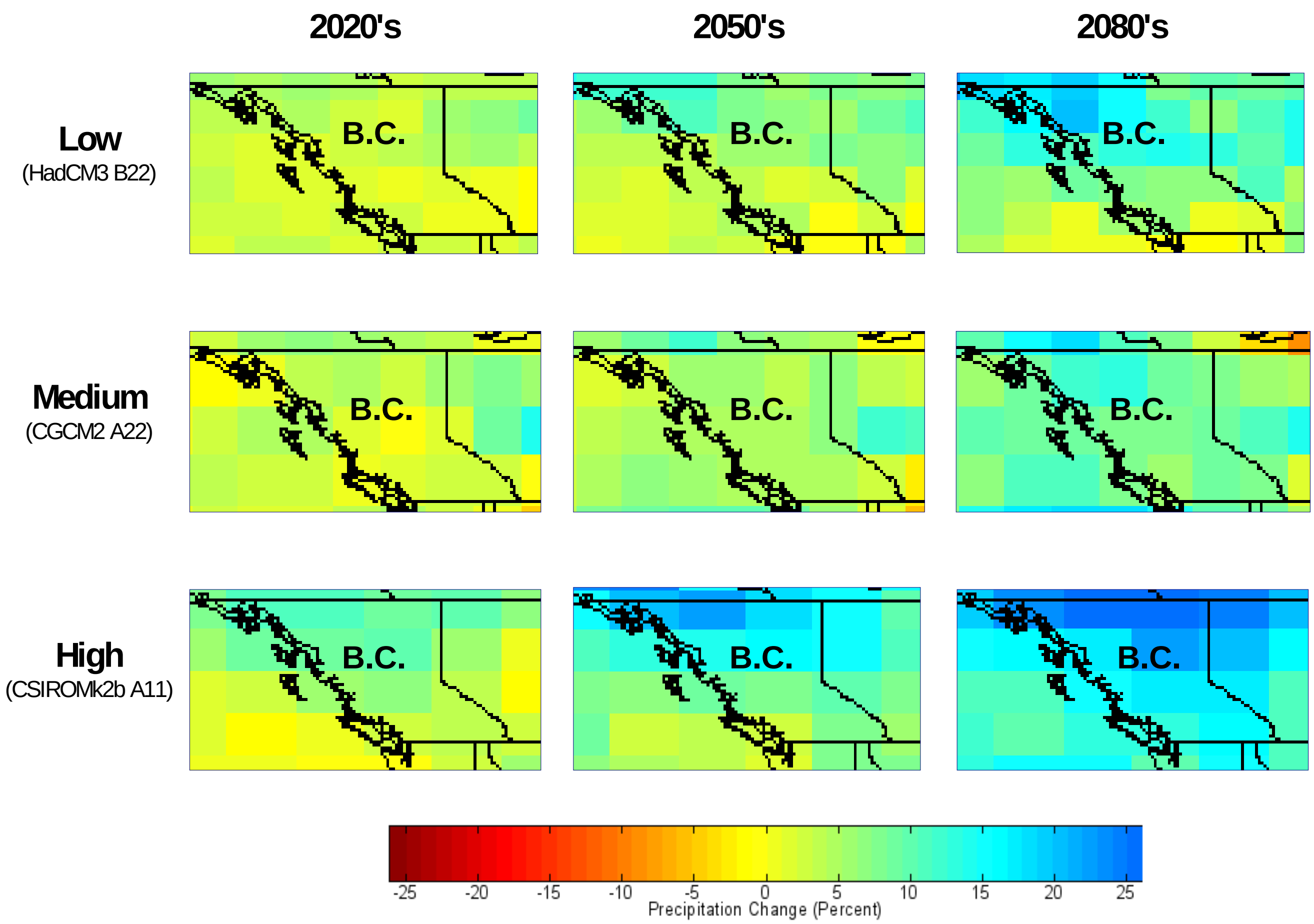


Figure 5: Summary of mean annual precipitation change for 2020's, 2050's and 2080's for a low, medium and high climate change scenario. Change is relative to the 1961-1990 model-simulated baseline period.

Source:
All data and maps prepared by the Pacific Climate Impacts Consortium; downloaded from http://www.pacificclimate.org/

2.2.3 Climate Change Impacts on Biodiversity in British Columbia

There has been ongoing interest in the potential impacts of climate change on biodiversity in British Columbia over the past decade or more. Some of the important milestone studies and reports during this period are described below.

Going back to 1997, Environment Canada initiated the Canada Country Study as a major national evaluation of the impacts of climate change. The Volume 1 workshop report, *Responding to Global Climate Change in British Columbia and Yukon* (Taylor and Taylor, 1997) marked the first major effort to inform policy makers and the public about the potential impacts of climate change in BC and Yukon. Biodiversity issues discussed include the potential impacts of sea level rise on wetlands, sea bird populations and other wildlife (Beckmann *et al.*, 1997); the impacts of climate change on plant communities in alpine ecosystems (Krannitz and Kesting, 1997); the impacts on biogeoclimatic zones (Hebda, 1997) and the impacts of wind pattern changes due to climate change on bird migration (Butler *et al*., 1997). The report also includes a high-level review article of the potential impacts of climate change on a wide variety of organisms, including mammals, terrestrial and aquatic invertebrates, plants, birds and fish (Harding and McCullum, 1997).

The *Indicators of Climate Change for British Columbia 2002* report (BC WLAP, 2002) includes discussion of several biodiversity issues, focused primarily at the species and ecosystem level. Beyond the climate indicators that were described above, the report describes trends relevant to a suite of indicators for terrestrial ecosystems (e.g., growing degree days), freshwater ecosystems (e.g., timing and volume of river flow), and marine ecosystems (e.g., sea surface temperature increase). Biodiversity issues discussed include the potential for declines in salmon populations due to increasing river and sea surface temperatures, impacts of increasing sea surface temperature and reduced food availability on Cassin's Auklet, and the contribution of warmer winters and increased growing degree days to an increase in the mountain pine beetle numbers.

In 2003, the Biodiversity Branch of the Ministry of Water Land and Air Protection commissioned an assessment of the threats to biodiversity and the gaps in protection. The resultant study entitled *Biodiversity Conservation in BC: An Assessment of Threats and Gaps* (Veridian, 2003), found that out of 17 different types of stressors, climate change posed the most significant threat to biodiversity in BC. They reached this conclusion by ranking the threats according to the magnitude of the impacts, the degree of change, the reversibility of the change, the geographic extent of the impact, the ecological amplitude, and the local distribution of the impacts. With regard to magnitude, impacts on processes or functions were ranked highest, followed by impacts on whole ecosystems, habitat elements, individual species (including keystone, rare, and focal species), and genes. The rationale behind this is that impacts on processes and functions can cascade down to ecosystems, habitats, individual species, and genes.

Table 1 presents a listing of both observed and projected impacts of climate change on biodiversity in BC. The list has been compiled based on a review of the above documents and additional reports provided, and supplemented by an overview keyword search of the primary literature. The list is not meant to be fully comprehensive, but rather to present an overview of impacts that have been identified in BC. Consistent with the assessment framework discussed above, each identified impact in the table includes:

Primary Climate Change Driver – e.g., increased temperature

Impact Mechanism (or Hypothesis as the case may be) – e.g., habitat loss

Environmental System – terrestrial, freshwater, or marine-linked

Biodiversity Level – ecosystem, species or genetic

Impact Range – local or widespread.

The circle coding in Table 1 is intended to provide a broad differentiation between impacts that have been observed (or documented scientifically), vs. those that are projected (or otherwise hypothesized). It must be noted that care should be taken in the extraction of results from Table 1. It is well understood that climate change and its impacts vary from one geographic location to another. For this reason, care must be taken when extrapolating conclusions from one study location to another. For similar reasons, conclusions from studies that are based on a broad review of the impacts literature should be treated with caution in the context of BC's highly variable and complex geography.

That said, summary highlights that can be drawn from Table 1 include:

- Increased temperatures are the most-often cited primary climate change driver. While this highlights the key role of temperature and heat accumulation in ecological systems, it also reflects the reality that future climate change predictions related to temperature are the most certain, followed by those for precipitation and other climate variables (e.g., wind, relative humidity). There is less certainty regarding derived variables (e.g., soil moisture), if such projections are available at all.
- Many studies draw impact conclusions that are linked across environmental systems.
- Many studies have impact mechanisms that are synergistically linked with other biodiversity impact mechanisms (e.g., habitat loss, invasive species).
- Impacts on genetic diversity are understudied, relative to impacts at the species or ecosystem levels.

Table 1: Observed and Projected Impacts of Climate Change on Biodiversity in British Columbia

Biodiversity Impact	System			Level			Range				
Description	terrestrial	freshwater	marine linked	ecosystem	species	genetic	local	widespread	Impact Mechanism / Hypothesis	Climate Change Driver	Reference
Increased mortality of coho salmon		●	●		●			●	Higher mortality in warmer years is expected as warmer water temperatures cause a decrease in food availability.	Increased sea surface temperature	Beamish and Mahnken 2001
Population decline in coho salmon		●	●		●			●	Reduced availability of prey species due to reduced marine productivity in warmer years.	Increased sea surface temperature	McFarlane et al 2000
Population decline in Thompson River coho salmon		●	●	○	●		●		Reduced marine productivity due to higher sea surface temperature (coupled with over-fishing).	Increased sea surface temperature	Bradford and Irvine 1999
Decline in Adams River sockeye salmon stock		●	○	○	●		●		Reduced freshwater productivity and reduced food availability for salmonids in key rearing habitat in Shuswap Lake.	Warmer water temperatures	Henderson 1992
Decline in Fraser River sockeye salmon		○	●	○	●			●	Increased pre-spawn mortality in the Fraser due to warmer sea surface temperatures, which cause the salmon to hold longer in the marine environment before beginning their migration.	Warmer water temperatures	Morrison et al 2002
Reduced spawning success of Okanagan sockeye salmon.		●	○		●		●		Delayed migrations that increase susceptibility to disease, reduce migration effectiveness and ultimately reduce spawning success.	Increased temperatures in freshwater systems	Hyatt et al 2003
Population decline in Cassin's Auklet; lower fledgling growth and potential for population decline in Rhinocerous Auklet on Triangle Island	●		●	○	●		●		Reduced prey availability due to warmer sea surface temperatures and changed migration of marine invertebrates.	Increased sea surface temperature	Bertram 2001
Reduced growth rate and increased mortality among tufted puffin fledgelings on Triangle Island	●		●	○	●		●		Reduced prey availability due to warmer sea surface temperatures and changed migration of marine invertebrates	Increased sea surface temperature	Gjerdrum et al 2003
Increased frequency of red tides and other harmful algal blooms off the Coast of Vancouver Island			●	○	●		●		Temperature regime more suitable for harmful algal species	Increased sea surface temperature	Mudie 2002
Decline in white sturgeon in the Fraser River		○		○	○		○		Increased water temperatures may result in salmon migration impacts that would reduce food availability for sturgeon. Also, changes in the annual hydrograph due to earlier spring melting will have uncertain effects.	Increased temperatures in freshwater systems	Solander 2005
South Purcell mountain caribou subpopulation is at high risk of extirpation and therefore vulnerable to any climate driven disturbance.	○				○	○	○		Habitat loss / degradation due to major fire or abnormally low snowpack or early snow melt.	Increased air temperatures; Decreased snowpack	Kinley 2001

●	Observed response
○	Projected / Hypothesized
	n/a or not yet identified

Table 1: Observed and Projected Impacts of Climate Change on Biodiversity in British Columbia - continued

Biodiversity Impact	System			Level			Range				
Description	terrestrial	freshwater	marine linked	ecosystem	species	genetic	local	widespread	Impact Mechanism / Hypothesis	Climate Change Driver	Reference
Range and abundance shift of bird species.	●				●			●	Warmer temperatures have caused these species (Surf Scoter; White-winged scoter; Wilson's Phalarope; Lewis' woodpecker; Swainson's thrush; and Yellow warbler) to either extend their range northwards or occupy the northern portion of their current range more densely.	Increased air temperatures	Bunnell and Squires 2005
Range expansion of invasive freshwater fish species such as small mouth bass and walleye.		●		○	●			●	Warmer freshwater temperatures will make habitat more suitable for the invasives, and less suitable for cold-water native species.	Increased temperatures in freshwater systems	Chu et al 2005
Lost forested habitat to pest outbreaks, particularly MPB.	●			●	○			●	Warmer temperatures increase the number of growing degree days for insects, which will enhance the MPB as well as other forest pests	Increased air temperatures	Logan 2003; Powell and Logan 2005
Accelerated colonization of MPB-killed stands by invasive species.	●			●	○			●	MPB will extend its range further north, and outbreaks will be more frequent and severe. This will kill stands of lodgepole pine.	Increased air temperatures; Increased winter minimum temperatures	Carroll et al 2004; Williams and Liebhold 2002
Trees species range shifts and abundance declines.	○			○	○			○	Climate change will alter current annual mean temperatures and precipitation patterns, shifting habitat quality away from what trees in that area are currently adapted to.	Increased air temperatures, changes in precipitation patterns	MOFR, 2006
Frequency and magnitude of insect pest outbreaks are expected to increase.	○			○	○			○	Climate change increases the number of growing degree days, enhancing the lifecycles of insect pests.	Increased air temperatures	MOFR, 2006
Forests will be damaged more often by extreme events.	○			○	○			○	The frequency of extreme events such as fires, droughts, and storms will increase, and corresponding damage to forests will result.	Increased frequency of extreme events.	MOFR, 2006
Range shift for large mammals; altered competitive species interactions.	○			○	○	○	○		Ecosystems are likely to shift 500 to 600m upwards in elevation in Glacier and Revelstoke National Parks with warmer temperatures.	Increase in average annual temperature	Scott and Suffling 2000
Inundation of wetlands in Glacier and Mount Revelstoke National Parks	○			○	○	○	○		Heavier runoff from glacial melt	Increase in average annual temperature	Scott and Suffling 2000
Invasive species such as knapweed and Russian thistle may expand in Kootenay National Park	○			○	○	○	○		Warmer temperatures will make the region more suitable for these invasive plant species	Increase in average annual temperature	Scott and Suffling 2000
Reduced availability of salmon will negatively impact terrestrial predators such as bears and eagles in Gwaii Haanas National Park Reserve	○	○	○	○	○	○	○		Warmer sea surface temperatures will enhance competitors of salmon, and increased runoff could impact salmon spawning beds.	Increased sea surface temperatures and increased precipitation in winter and spring.	Scott and Suffling 2000
Potential for: Loss of alpine meadows, Increase in major insect outbreaks, Reduced snowpack at low/moderate elevations.	○	○		○	○		○		Generally warmer and wetter (annual) climate change scenarios linked to existing research on ecosystem migrations, hydrology, etc.	Increase in annual/seasonal temperature; Increase in annual precipitation	Compass 2006

●	Observed response
○	Projected / Hypothesized
	n/a or not yet identified

Table 1: Observed and Projected Impacts of Climate Change on Biodiversity in British Columbia - continued

Biodiversity Impact	System			Level			Range				
Description	terrestrial	freshwater	marine linked	ecosystem	species	genetic	local	widespread	Impact Mechanism / Hypothesis	Climate Change Driver	Reference
Habitat loss in freshwater streams from increased erosion and sedimentation.		○		○	○			○	Enhanced winter flow due to glacial melt and increased precipitation during winter and spring likely to erode river banks and cause sedimentation elsewhere	Increased winter temperatures, increased winter/spring precipitation	MoE 2005
Ephemeral wetlands in the Fraser lowlands may dry up.		○		○			○		Increased annual temperatures coupled with dyking in the Fraser lowlands will dry up/ inhibit the recharge of ephemeral wetlands	Increased annual temperatures	MoE 2005
Freshwater ecosystem community structures and functions are likely to shift.		○		○	○	○		○	Loss of streamside vegetation plus climate change increases stream temperatures and changes community structure: species with a narrow temperature range may be extirpated.	Increased temperatures in freshwater systems	MoE 2005
Loss of native riparian vegetation; advance of invasives.	○	○		○	○	○		○	Water stress could extirpate vegetation with poor drought resistance in riparian areas since ponds and streams are likely to be lower due to high temperatures.	Increased annual temperatures	MoE 2005
Two identified species - streaked horned lark and alpine anemone - are likely to be extirpated in the lower mainland, six others may experience range shifts.	○				○		○		Climate change may reduce the availability of habitats and act synergistically with other stressors like habitat loss.	Increased annual temperatures; reduced snowpack, etc.	MoE 2005
Potential extirpation of shore birds.	○		○	○	○	○	○	○	Sea level rise and increased storm frequency could be destructive to shorebird nesting sites. Nest loss due to flooding is expected to increase in the Georgia Depression.	Sea level rise	Beckmann et al 1997
Wetland waterlogging, altered wetland plant communities		○	○	○	○	○	○	○	Coastal wetlands could be waterlogged repeatedly due to sea level rise and increased storm surge Salt water tolerant plants will be favoured over freshwater plants, and some plants will drown.	Sea level rise, increase in storm events	Beckmann et al 1997
Reduction in food for seabirds	○		○	○	○	○		○	Increased runoff and precipitation will increase coastal water turbidity, reducing the availability of fish in these areas which are fed on by piscivorous shorebirds. Plants foraged on by other seabirds may be submerged too deeply for seabird access due to sea level rise.	Sea level rise, increase in storm events	Beckmann et al 1997
Rare mosses will undergo a range contraction and possibly be extirpated.	○				○	○		○	Dryer summer conditions in BC could reduce the suitability of coastal forests as habitat for rare mosses and other bryophytes. These may undergo range expansions into the Yukon.	Increased annual temperatures; Decreased summer precipitation	Harding and McCullum 1997

●	Observed response
○	Projected / Hypothesized
	n/a or not yet identified

Table 1: Observed and Projected Impacts of Climate Change on Biodiversity in British Columbia - continued

Biodiversity Impact	System			Level			Range				
Description	terrestrial	freshwater	marine linked	ecosystem	species	genetic	local	widespread	Impact Mechanism / Hypothesis	Climate Change Driver	Reference
Cold-blooded invertebrates will need to shift their ranges or will be extirpated. Synergistic impact with habitat fragmentation.	○	○	○		○	○		○	Cold-blooded species will be very vulnerable to changes in temperature because their metabolic processes are heavily influenced by ambient temperature. If these species are unable to migrate to more suitable areas whilst climate changes, they will be extirpated	Increased annual temperature	Harding and McCullum 1997
New parasites and diseases will be present in B.C.	○	○	○	○	○	○		○	As temperature increases, BC will become habitable for parasites and diseases that were previously limited by cold temperatures.	Increased annual temperatures	Harding and McCullum 1997
Some lichen species may expand their range into BC, while others may suffer range contractions.	○				○	○		○	Warmer temperatures may cause range migrations in lichen species at both the northern and southern edge of their current ranges.	Increased annual temperatures	Harding and McCullum 1997
Ungulates may experience range and abundance shifts.	○				○	○		○	Warmer temperatures are expected to result in snow that is more dense and more difficult for ungulates to travel through. This could alter ungulate distributions.	Increased annual temperatures	Harding and McCullum 1997
Some rare small mammals (shrews, voles, mice) may have a range expansion in BC, while others could have a range contraction.	○				○	○		○	Small mammals at the northern limit of their range in BC are likely to expand their ranges and benefit as a result warmer temperatures. Those at the southern limit of their ranges may be able to colonize habitats at higher altitudes.	Increased annual temperatures	Harding and McCullum 1997
Eight bat species that are rare or endangered may benefit from range expansions in BC.	○				○	○		○	The warmer climate will allow eight rare and endangered bat species, which are at the northern edge of their range, to expand their range within BC.	Increased annual temperatures	Harding and McCullum 1997
Potential loss of genetic diversity among fish		○			○	○		○	Genetically distinct fish stocks that are at the southern-most edge of their range in BC could be extirpated as a result of warming.	Increased annual temperatures	Harding and McCullum 1997
Abundance declines of sandpipers.	○				○			○	Air currents are expected to change as a result of climate change and this could disrupt sandpiper migration routes. Models suggest that this would ultimately reduce the reproductive fitness of female sandpipers by about 3%.	Increased annual temperatures	Butler et al 1997

●	Observed response
○	Projected / Hypothesized
	n/a or not yet identified

Table 1: Observed and Projected Impacts of Climate Change on Biodiversity in British Columbia - continued

Biodiversity Impact	System			Level			Range				
Description	terrestrial	freshwater	marine linked	ecosystem	species	genetic	local	widespread	Impact Mechanism / Hypothesis	Climate Change Driver	Reference
Tree-line shift in alpine tundra	○			○	○		○		Increased temperatures will shift alpine tundra ecosystems higher up. Expected loss of populations and perhaps, species is predicted with climate change.	Rising temperatures	Hebda 1994
Shrinkage of wetland area in southern and central interior BC	○	○		○	○		○		With moisture loss, wetland areas are expected to shrink in southern and central interior BC. Native species may decline or be extirpated, enabling invasive weeds to thrive.	Temperature and precipitation changes leading to moisture loss.	Hebda 1994
Shifts in vegetative distribution in the BC Interior	○			○	○		○		Anticipated disappearance of large tracts of forest and the upward and northward expansion of open vegetation in the dry interior of BC (rather than simple species replacement, as in more moist, forested regions).	Rising annual mean temperatures	Hebda 1994
Species decline or re-distributions in estuaries	○		○	○	○		○		Sea-level rise may drown low-lying coastal plant communities and substantially modify shoreline morphology resulting in species-level impacts.	Rising sea-level	Hebda 1994
Impacts on three key climate-sensitive resources in the Pacific Northwest (PNW): freshwater, salmon, and forests.	○	○		○	○		○		Correlations developed using past and predicted features of regional climate in the PNW, i.e., snowpack, flow and temperature changes in freshwater, etc. Links with salmon abundance and with forest growth and disturbance mechanisms.	Increased temperatures resulting in the reduction of regional snowpack.	Mote 2003.
Potential range expansion of the Behr's Hairstreak butterfly, interior grasslands, Western Redcedar, and Gary Oak	○				○			○	Projected changes in future climate (temperature and precipitation) used to forecast the range of climatic suitability for each species.	Changes in mean annual temperature and precipitation.	PCIC and RBCM 2007
Potential reduction in Coho salmon populations.		○	○		○			○	Altered Aleutian Low-Pressure System resulting in changing patterns of large river flow patterns, snow pack levels, and sea surface temperatures. Hypothesized impacts to habitat and food availability.	Reduced river flows and increased sea temperature.	Beamish 1999; Beamish et al. 2000
Decline in steelhead (Oncorhynchus mykiss) recruitment at the Keogh River.		●	●		●		●		Declines in survival during both freshwater and marine life stages correlated with changes in climatic factors.	Temperature increase, flow alteration, insect production	Ward 2000
Reduced fitness of Fraser River sockeye salmon.		●	●		●		●		Elevated sea surface temperatures that cause increased metabolic demand, or influence food acquisition.	Rising Sea Surface Temperatures	Cox 1997

●	Observed response
○	Projected / Hypothesized
	n/a or not yet identified

Table 1: Observed and Projected Impacts of Climate Change on Biodiversity in British Columbia - continued

Biodiversity Impact	System			Level			Range				
Description	terrestrial	freshwater	marine linked	ecosystem	species	genetic	local	widespread	Impact Mechanism / Hypothesis	Climate Change Driver	Reference
Potential extirpation of sockeye salmon			○		●		●		Increased sea surface temperatures large enough to shift the position of the thermal limits into the Bering Sea. Such an increase would potentially exclude sockeye salmon from the entire Pacific Ocean and severely restrict the overall area of the marine environment that would support growth.	Rising Sea Surface Temperatures	Welch et al. 1998
Salmon abundance varies in relationship to climate.			●		●		●		Correlations with catch data used to describe how climatic factors affecting the marine environment play a significant role in salmon production on interannual and interdecadal time scales.	Rising Sea Surface Temperatures	Downton et al. 1998
Impact on migration of adult sockeye salmon		●			●	○	●		Water temperature and flows have an impact on the migratory rates of sockeye salmon (Oncorhynchus nerka) in the Columbia River	Temperature increase, flow alteration	Quinn et al. 1997
Reduced salmon spawning success		○			●		●		Future predictions in the Fraser River system suggest modest average flow increases but significant peak flow increases. Increased water temperatures above the 20oC spawning success threshold predicted.	Temperature increase, flow alteration	Morrison et al. 2002
Altered zooplankton community structure and subsequent pelagic food web impacts (fish and birds).			●		●		●		Ocean climate fluctuations, in particular changing temperature and current patterns, cause immediate responses in zooplankton community composition. Subsequent impacts on pelagic foodweb (fish and coastal seabirds) are correlated.	Ocean current patterns, sea surface temperature	Mackas et al. 2001
Reduced juvenile salmon survival rates.		○	○		●		●		Using oceanic, coastal and freshwater climate indices and simulations of bioenergetics of key predators (e.g., northern squawfish) predicted that warmer climatic conditions lead to an increase in predation in the range of 26–31%.	Increased freshwater temperatures	Petersen et al. 2001

●	Observed response
○	Projected / Hypothesized
	n/a or not yet identified

Reflecting on the information currently available in BC (i.e., Table 1), a recent survey of species and ecosystem experts and managers across the province (Compass, 2007) and the broader literature on potential climate change impacts (e.g., Lovejoy and Hannah, 2006) we can highlight some of the highest priority threats to biodiversity in BC as a result of climate change. These are summarized in Table 2 on the next page.

Special Note on Synergistic Effects

Climate change has synergistic effects with many of the biggest existing impacts to biodiversity. Many authors in Lovejoy and Hannah (2005) stress concern that potential climate change impacts on biodiversity will be occurring in concert with other already well-established stressors. Specific examples evident in BC include:

Habitat loss and fragmentation:
With sea level rise, coastal marshes, wetlands, and mudflats may migrate further inland. However, this process will be constrained by built environments such as the extensive dike systems of the Fraser and Squamish River estuaries (Beckmann, 1997, BC MOE 2005). Here, habitat fragmentation, in the form of dikes, could act synergistically with climate change, reducing and potentially eliminating wetlands and mudflats in the Fraser River floodplain.

Invasive species:
Increasing lake and river temperatures in BC make for more suitable habitat for invasive warm-water fish species such as yellow perch and walleye (Chu et al 2005). These species have the potential to outcompete native cold-water species, which are less suited to warmer water temperatures. In this example, warming acts synergistically with invasive species to pose a threat to native fish species. Similarly, warmer, dryer temperatures in Kootenay national park resulting from climate change are less suitable for native plants, and more suitable for invasives such as Russian thistle and Knapweed (Scott and Suffling, 2000). In this case also, invasive species and climate change act synergistically, threatening native plants.

Species exploitation
Synergistic action between commercial harvesting and climate change has already been observed to reduce Thompson River Coho stocks by up to 90% (Bradford and Irvine, 1999). Increases in river and lake water temperatures are expected to have detrimental impacts on Fraser River sockeye stocks, which are also heavily harvested (Morrison, 2002). A similar synergistic effect could be expected for sockeye.

Environmental contamination
Nutrient enrichment from agricultural runoff could act synergistically with warming water temperatures due to climate change to enhance eutrophication in freshwater systems.

Table 2: Summary of Priority Climate Change Threats to Biodiversity in BC	
Species at risk	Although there could be some benefits for at risk species, in general there is significant concern for species at risk that are already threatened by small population size, loss of unique habitats and low reproduction/dispersal rates (among other causes). Any potential for climate change to further exacerbate these existing causes could greatly increase the risk of extinction.
Aquatic habitat	In rainfall driven streams, extended summer low flow periods are expected. This will further increase water temperature, favouring warm water species, and altering community structure and functioning. Conversely, in snowmelt driven and glacier fed streams, the magnitude and duration of summer floods is expected to increase. In either case, significant impacts on aquatic habitats should be expected.
Wetlands	Wetlands are particularly vulnerable to climate change. As physiographically limited systems they are unable to migrate, and hence, vulnerable to changes in hydrology, nutrient inputs, etc.
Coastal ecosystems	The sea is rising. Coastal ecosystems – including tidal zones, estuaries and coastal wetlands – and the species that utilize them will all experience impacts. Specific challenges to be faced include: salt water intrusion causing changes in local soil chemistry and subsequent extirpation of freshwater plants; habitat loss for migrating shorebirds; the destructive force of storm surges; and alteration of foodweb dynamics for seabirds and other animals.
Alpine ecosystems	Given their restricted geographic area and narrow elevation range, alpine ecosystems are particularly vulnerable to climate change. Climate and vegetation change rapidly with altitude over relatively short distances in mountainous terrain. As a result, alpine ecosystems are particularly vulnerable to encroachment by lower elevation ecosystems.
Forest and grassland ecosystems	The current MPB epidemic is the largest ever recorded. Ongoing concerns are the increased potential for major widespread wildfires, and the subsequent potential for transformations in disturbed ecosystems, such as colonization by invasive species and resultant new species assemblages. Grassland ecosystems may expand in range, yet face threats in terms of lost species diversity.
Invasive species	Climate change may expedite the colonization of some areas by invasive species in both the terrestrial and freshwater realms. For instance, invasive warm water fish species in BC, such as yellow perch and small and large-mouth bass, may thrive as water temperatures increase. These species may out-compete or predate on cold- water native species. Similarly, increased frequency and magnitude of forest disturbances will create openings vulnerable to colonization by invasive plants
Ecosystem representation in protected areas	Protected areas are widely acknowledged as one of the most important management instruments for biodiversity conservation. In BC, the protected areas strategy in the 1990's set out to improve the protection of representative ecosystems using both biogeoclimatic and ecoregional classification systems. The potential for major, long-term ecosystem shifts under a changing climate suggests a need to re-evaluate the protection of representative ecosystems with a stronger focus on the ecoregional system as it is based on broad topographical features that do not shift with climate change.

3. Biodiversity Management under a Changing Climate

Globally, two broad policy responses to address climate change have been identified. The first is "mitigation", which refers to actions aimed at slowing down climate change by reducing net greenhouse gases (GHG) emissions. The second is "adaptation", which refers to actions taken in response to, or in anticipation of, projected or actual changes in climate.

In BC, the Province describes it's overall climate change action plan in the 2004 document entitled "*Weather, Climate and the Future: BC's Plan*" (BC WLAP, 2004). The Plan lists 40 mitigation and adaptation actions that the government is undertaking or will undertake to address climate change. The actions are grouped into five main categories:

> **Sustainable Energy Production and Efficient Use –** enhancing energy conservation and efficiency in industry, small business.
>
> **Efficient Infrastructure: Transportation, Buildings and Communities –** increasing efficiency and promoting opportunities for innovation.
>
> **Sustainable Forest and Carbon Sink Management –** managing forest and agricultural lands to increase carbon sequestration and decrease impacts.
>
> **Government Leadership and Outreach –** reducing emissions from government operations, increasing capacity to adapt, increasing public outreach on mitigation and adaptation.
>
> **Water Management –** supporting research geared towards developing water resource management tools, and supporting integrated watershed management to address issues such as drought and flooding.

The plan is weighted toward mitigation, or GHG management actions, and there is no specific mention of actions to address potential biodiversity impacts.

3.1 Mitigation

Global reductions in GHG concentrations are expected to slow the rate and magnitude of climate change over the long term. To do this, both sources of and sinks for greenhouse gases must be managed. Examples are using fossil fuels more efficiently and expanding forests to sequester greater amounts of carbon dioxide from the atmosphere.

Broadly speaking, any efforts to reduce the rate or magnitude of climate change by reducing atmospheric GHG concentrations can be viewed as a long-term activity toward mitigating impacts on biodiversity at all levels. Therefore, developing strategies that reduce GHG emissions and maximize the carbon sequestration potential in living systems should be viewed as critical elements in minimizing the long-term impacts on biodiversity in British Columbia.

The stated goal of the BC Plan (BC WLAP, 2004) is to maintain or improve upon the Province's ranking of third-lowest per-capita GHG emissions in Canada. The BC Ministry of Environment Service Plan is tracking performance toward this goal. The BC Government Strategic Plan 2006/07 – 2007/08, released as part of BC's Budget 2006, confirms this target, and also states that "BC currently has more greenhouse gas emissions per capita than Oregon, but less than Washington. The 2015/16 target is to improve BC's ranking." Unfortunately however, the use of a "per-capita" GHG emissions target still allows for an absolute growth of GHG emissions in BC over time. A related issue is that the Plan lacks absolute targets, which will make reporting out on the success of actions on actual GHG reductions difficult.

GHG management is a global issue, and mitigation efforts in BC can rightfully be placed in this context. For example, the World Business Council for Sustainable Development (WBCSD, 2005) indicates that North Americans in general have the highest per capita GHG emissions, and face considerable challenges in achieving improved energy efficiency. As a vivid local example, a recent discussion paper for the Greater Vancouver Regional District (GVRD, 2006) indicates that in order to meet Kyoto targets in the region would require GHG emission reductions equivalent to 90% of all automobile emissions. What this discussion clearly highlights is that additional mitigation efforts are possible, but implementing them will require difficult societal trade-offs.

3.2 Adaptation

Regardless of whether countries around the world succeed in achieving major reductions in GHG emissions, climate change models predict that excess greenhouse gases already in the atmosphere will drive climate change and its impacts for centuries to come. As a result, the need to implement activities aimed at adapting to the potential changes is imperative.

There are two broad types of adaptation actions. First, **capacity-building actions** aim to increase the capacity of institutions, governments, businesses, and the public to prepare for climate change. Capacity-building actions include research and assessment, monitoring, extension and training, changes in policies, etc. The second type, **implementation actions,** conveys actual adaptation benefits 'on the ground'. Implementation actions most often aim to eliminate a projected climate change impact, however in some cases implementation actions can be aimed at exploiting a climate change opportunity.

Many initiatives are underway in BC related to climate change adaptation, primarily of the capacity-building type. A number of these initiatives are highlighted below.

The BC Government's plan (BC WLAP, 2004) described above contains a number of specific actions to increase provincial capacity to adapt. Examples include:

- Addressing climate change and extreme weather in government planning and operations;

- Implementing effective monitoring and reporting procedures for climate change and its impacts;
- Developing climate models and other tools for addressing climate change risks and adaptation options;
- Supporting applied climate change research that meets the needs of decision-makers; and
- Developing capacity throughout BC to respond to extreme weather and climate change.

The Climate Change Section (CCS) of MoE's Environmental Quality Branch leads implementation of the capacity-building actions. CCS staff participate in and fund climate impacts and adaptation research and plan development efforts, and work within MoE and with other ministries to increase government capacity to prepare for climate change. Some of these CCS initiatives relate directly to biodiversity. Outreach on impacts and adaptation and mitigation is achieved through active participation in workshops and conferences around the province. Their website (http://www.env.gov.bc.ca/air/climate/) houses government documents regarding its actions and those of partner organizations.

The Ministry of Forests and Range (MoFR) established a Climate Change Task Team in June 2005 for the purpose of preparing a report for the Chief Forester on how the MoFR should strategically position itself with respect to the potential impacts of climate change on the province's forest resources. Their report *Preparing for Climate Change: Adapting to Impacts on British Columbia's Forest and Range Resources* (BC MoFR, 2006), presents an overview of climate change and potential biophysical (and socio-economic) impacts on the forest sector. The report probes specific management issues related to silviculture and forest genetics, forest health, and fire management and in each case outlines possible adaptive responses. It concludes with a comprehensive list of recommendations that fall into three categories: A: improving knowledge through analysis and research; B: Reviewing operational policies and practices; C: Building awareness and capacity within and outside the ministry. Implementation of selected recommendations will be coordinated through the broader Future Forest Ecosystems Initiative (FFEI, 2006), which has identified ecosystem resilience as an important management goal, and identified a specific objective to predict how climate change might alter the range of natural variability of ecosystem components.

The Water Stewardship Division (WSD) of the Ministry of Environment has not yet undertaken a similar exercise to fully examine the potential of climate change on the province's freshwater resources. However, WSD staff participate in applied research projects that consider the impacts of climate change on surface and groundwater in BC, and in drought and flood management initiatives that will likely convey adaptation benefits. WSD is sponsoring in cooperation with the Pacific Climate Impacts Consortium a workshop on hydrological modelling tools that work with climate change scenarios. WSD is funding a comprehensive review of sea level rise to inform policy on sea dike standards and coastal development guidelines. WSD staff is participating with PCIC in conducting province-wide face-to-face consultations with water users to assess their views on climate change impacts and adaptation. The River Forecasting Centre now considers climate change a major factor in increasing flood risks and altering river hydrology and is seeking to improve forecasting capacity to account for climate change.

The Pacific Climate Impacts Consortium (PCIC) was established at the University of Victoria in 2005 with a mandate to produce practical climate information for education, policy, and decision-making in the Pacific Northwest. Funding, in-kind support and project partners include the BC Ministry of Environment, BC Hydro, BC Ministry of Forests, C-CIARN BC; Greater Vancouver Regional District; Columbia Basin Trust; Columbia Power; Nature Trust; and the University of BC. PCIC carries out applied research and provides climate information and interpretations. They make several online tools available for studying climate change, including climate scenario data and maps that can be used for impact assessment or education purposes. For example, in collaboration with the Royal BC Museum and a number of others, PCIC has created high-resolution maps of climate variables and other biophysical parameters (e.g., distribution of tree species) under future climate scenarios for BC PCIC is currently leading the development of a strategy for research on climate change and hydrology in BC.

Table 3 presents a listing of the adaptation efforts that have been identified related to climate change and biodiversity management in BC. The list is not meant to be fully comprehensive, but rather to present an overview of actions that have been identified in BC. The list has been compiled based on a review of the above sources and additional reports provided, and supplemented by an overview keyword search of the primary literature.

It must be emphasized that this list is limited to actions either currently being implemented or recommended for implementation that are specific to biodiversity management in response to climate change in BC. Many other biodiversity management activities are undoubtedly underway that are supportive of climate change adaptation, yet not yet explicitly linked to it. Documenting the ways and means to which such actions of this type are already built into the current provincial management structure was beyond the scope of this review.

Each identified action in the table is categorized according to both the type of adaptation activity, and the biodiversity impact target as follows:

Type

Capacity-building – broken down into three categories: i) research, monitoring and assessment, ii) education and extension, iii) plans and policies.

Implementation – direct, on-the-ground action aimed at addressing a current or projected climate change impact.

Biodiversity Impact Target

Environmental System – terrestrial, freshwater, or marine-linked

Biodiversity Level – ecosystem, species or genetic

Impact Range – local or widespread

The circle coding in "type" column of Table 3 is intended to differentiation between actions that are currently underway in BC vs. those that have only been recommended. The circle coding in "target" column differentiates between primary aims and secondary benefits.

Some highlights of this compilation include:

- The vast majority of adaptation actions are of the capacity-building type. All current actions involve research, monitoring, education, planning, etc. There are no known implementation actions underway.
- Other than generic recommended actions, very few actions have been identified for freshwater systems.
- Most activities are 'wide-spread' meaning that they reflect high-level guidance. Very few, if any, actions directly target specific locations or biodiversity hotspots (although many in theory could if implemented in specific locations).

Table 3: Climate Adaptation Management Actions (Current and Recommended) in British Columbia

Adaptation Action					Biodiversity Target								
	Capacity Building				System			Level			Range		
Description	research / monitoring / assessment	education / extension	plans / policies	Implementation	terrestrial	freshwater	marine linked	ecosystem	species	genetic	Local	widespread	Reference
Implement monitoring and reporting procedures for climate change and its impacts	●				●	●		●	○	○		●	
Modelling and other data collection techniques are being improved in order to better study how ecosystems may shift as a result of climate change.	●				●	●		●	○	○		●	BC WLAP 2004
Support knowledge transfer and build capacity to respond to extreme weather events (flood, drought, fire).	●	●			●	●		●				●	
Develop climate change projection models and a climate change monitoring system to project future climates and to monitor changes to forest ecosystems as a result of climate change	○				●			●	○		○	●	
Develop tools for evaluating impacts of climate change on natural disturbance processes	●				●			●	○		○	●	
Conduct risk assessments to determine potential impacts of climate change on forest and range resources	○		○		●			●	○		○	●	FFEI, 2006
Conduct research and modelling to determine potential impacts of climate change on key species, tree seed genotypes, soil processes and productivity, and fire regimes	○				●			○	●	●	○	●	
Use communication to increase awareness and understanding of climate change impacts on B.C.'s forests		●			●			●			○	●	
Development of i) climate-based seed planning zones, ii) climate profiles for provenances, species and genotypes, and iii) high spatial resolution climate data for climate change analysis.	●				●			●	●	●	○	●	
Improve knowledge through research and analysis (e.g., seedlot trials, species shifts, impact assessments, etc.)	○				●			●	●	●	●	●	
Review and modify operational policies and practices (e.g., modify seed transfer limits, increase species and genetic diversity in plantations, etc.)	○			○	●			●	●	●	●	●	BC MoFR 2006
Build awareness and capacity within and outside the ministry.		○			○			○	○	○	○	○	
Facilitate migration of species and populations to take advantage of warmer climate opportunities.				○	●				●	○	○	●	
Assessment of ecosystem and tree species changes in extent, elevation, and spatial distribution under climate change scenarios.	●	○			●			●	●	●		●	Hamann et al 2004

●	Currently underway
○	Recommended
	N/A

●	Primary target
○	Secondary benefits
	N/A

Table 3: Climate Adaptation Management Actions (Current and Recommended) in British Columbia – cont'd

Adaptation Action					Biodiversity Target									
	Capacity Building				System			Level			Range		
Description	research / monitoring / assessment	education / extension	plans / policies	Implementation	terrestrial	freshwater	marine linked	ecosystem	species	genetic	Local	widespread	Reference
Forests: Avoid habitat fragmentation, provide connectivity, maintain natural disturbance regimes, protect climate refugia, protect functional groups and keystone species, assist migrations, etc.			○	○	●			●	●	●	○	●	BC MoE 2005 and Hansen et al 2003
Alpine habitats: establish conservation networks, designate wildlife corridors through montane areas, limit recreation, etc.			○	○	●			●	●	●	○	●	
Freshwater habitats: maintain riparian habitats to protect thermal regimes, avoid invasion of exotic species, remove barriers to flow such as dams and dykes, maintain connectivity between wetlands, etc.			○	○		●		●	●	●	○	●	
Expand and improve: stewardship support, education, research and monitoring.	○	○	○	○	○	○		○	○	○	○	○	
Set up ecological monitoring programs to establish trends for climate tolerance; rates of change; migration ability; and reproductive success	○				●	●	○	●	●	○		●	
Expand modelling of impacts on ecosystems and species of interest.	○				●	●	○	●	●			●	
Build capacity of management professionals to integrate climate change into planning and management.		○			○	○	○	○	○	○		○	
Direct intervention where appropriate (e.g., habitat restoration, species recovery programs, assisted migration, and captive breeding programs)				○	●	●			●		●		
Gene management: determine limits of species and genotype transferability, plant a mixture of provenances at a site, etc.	○			○	●					●		●	Spittlehouse and Stewart 2003
Forest protection: develop "fire-smart" landscapes, shorten rotation lengths to reduce vulnerability to insects and facilitate change to more suitable species, etc.	○			○	●			●				●	
Non-timber resources: minimize habitat fragmentation and increase connectivity, etc.				○	●	○		●	●	●		●	
System planning and policy: expand protected area networks, improve connectivity of protected area systems, etc.			○	○	●	○		●	●	●	○		Scott and Lemieux 2005
Protected area management: implement ex-situ conservation and translocations, create/restore buffer zones around protected areas, etc.				○	●	○		●	●	●	○		
Research and monitoring: utilize parks for long-term integrated monitoring sites, conduct climate change impact assessments, etc.	○				○	○		○	○	○	○		
Capacity building and awareness: strengthen professional training, develop partnerships/collaborations with park stakeholders, etc.		○			○	○		○	○	○	○		
Assessment of the impacts of climate change on the distribution of various bird species	●				●				●	○		●	Bunnell & Squires 2005
Studies are underway to determine the impacts of snowpack variation on lichen for mountain caribou	●				●				●		●		Kellner et al 2006
Management Plan for Mount Assiniboine Provincial Park	○	○	○	○	●	●		●	●	○	●		Compass 2006

●	Currently underway
○	Recommended
	N/A

●	Primary target
○	Secondary benefits
	N/A

4. Discussion

To a large degree the types of climate change impacts and potential management actions identified at the global scale (see Lovejoy & Hannah 2005) are evident in BC.
It is becoming clear that BC can expect major transformations in biodiversity across all systems (terrestrial, freshwater, marine-linked) and all levels (genetic, species, ecosystems) under a changing climate. From a management perspective this may require a reality check. What are the realistic goals for biodiversity management in a time of rapid climate change? To what extent should managers pursue aggressive adaptation actions (e.g., species translocations, captive breeding)? Such questions imply that it will become increasingly important to identify clear management objectives to guide management priorities.

The literature suggests that maintaining ecosystem resilience, focusing on the underlying structure, functions, and processes of ecosystems should be a priority. As noted by many authors, implementing "good current conservation practice", such as creating protected areas and biodiversity networks, minimizing habitat fragmentation and managing invasive species, is the obvious starting point for biodiversity management in response to climate change. In this sense, the vast majority of "options" for managing biodiversity with climate change in mind are already well known. In short, we know in principle what to do, what is not well known is where, when and how to do it.

In BC, like elsewhere, the management emphasis to date has been on capacity building rather than implementation. This is understandable given the current level of uncertainty of potential climate change impacts. However, as societal understanding of the issues increases, we can expect a parallel rise in the call for more implementation action.

While many of the implementation challenges associated with biodiversity conservation are the same for climate change impacts as from other types of impacts, there are a few that are unique and require special attention here in BC.

How Far for SAR?

It is a management risk to immediately assume that the greatest biodiversity impact should be the greatest focus of management effort. In some cases it may be necessary to accept losses and preserve scarce resources for investments in other achievable biodiversity conservation improvements. The development of protection plans for species at risk that are currently at the extreme southern edge of their climate range in BC provide a possible example. To what extent should management action be taken to preserve a species if its future climate and habitat range shifts entirely outside of BC?

Non-Native or Newly-Native?

Scott and Lemieux (2005) outline this complex policy dilemma involving the formal definitions of "non-native" or "alien" species, and "historical range". For example, consider how future changes in climate may increase the potential for some species to expand their range into new or open ecological niches – say, northward shifts of species across the US border. On the one hand, these species could be considered as non-native or invasive species requiring active eradication policies. On the other hand, the arrival of new species may in fact signal successful autonomous adaptation by a species into a new climate refuge. What this suggests is that invasive species "impacts" and the potential options for managing them will need to be considered on a case-by-case basis.

Identifying No-Regrets Actions

There is a need to guard against management inactivity in the face of the major uncertainties raised by climate change. In all cases we should be looking for "no-regrets" actions. These are actions that perform well under current climate or any future climate scenario, i.e., they perform well irrespective of climate change. Other features that make no-regrets options reasonable may include: i) relatively low life cycle cost, ii) a short completion horizon, and iii) limited risk to other management objectives (e.g., cost, other competing environmental objectives). Incorporating habitat restoration activities into MPB-response plans, or expanding protected area boundaries in areas with fewer resource development opportunities are some possible examples to consider.

Mitigation

BC has a goal to remain among the lowest per-capita GHG emissions levels in Canada. This goal and all of the specific actions related to reducing emissions and increasing carbon sequestration should be rigorously supported for their long-term potential to stabilize climate change and ultimately limit biodiversity impacts.

The potential to select mitigation actions that have complementary adaptation benefits, and vice versa, is currently gaining popularity in the literature. Restoration of degraded landscapes with vegetation and the implementation of agroforestry systems are two examples where carbon sequestration benefits can be achieved simultaneously with reduced soil erosion and improved water quality, both of which can provide biodiversity conservation benefits (Watson, 2005).

5. Data Gaps

In terms of the *genes/species/ecosystems* X *terrestrial/freshwater* framework used in this study, it appears that there has been much more consideration of potential climate change impacts in the terrestrial realm than in the freshwater (notwithstanding all of the attention on salmon). This implies that a general increase in the freshwater realm is in order.

There has also been more consideration of potential climate change impacts at the ecosystem level, although some specific species at risk plans are underway that identify climate change as a potential threat, and policies for the management of "identified wildlife" do already exist. There may be a lack of current attention on understanding impacts at the genetic level.

There has been relatively higher focus placed on impacts associated with changes in mean annual or seasonal temperature than in other climate drivers. Given that there is strong evidence that climate extremes play a dominant role in many impact processes (Parmesan, 2005) it seems that more attention in BC is required on the potential for changes in the magnitude and frequency of extreme weather events.

In overview, there are three broad areas that stand out as data gaps in need of further development and refinement:

Develop a Focused Biodiversity and Climate Change Research Agenda

It is understandable that research is the primary focus of current climate change and biodiversity management efforts in BC. There is still clearly a great deal to be learned about the potential magnitude and rate of climate change at the regional and local levels, and subsequent impacts on the full range of biodiversity endpoints. Given the reality of scarce resources however, effort should be made to develop a focused research agenda in order to maximize the practical benefit of research investments. Considerations in developing that agenda should include:

- The priority climate change threats to biodiversity in BC (i.e., Table 2),
- The current gaps in existing knowledge (e.g., research in the freshwater realm is under-represented),
- Linking information requirements to the specific needs of assessing feasible climate change mitigation and adaptation options for biodiversity management.

Develop a More Complete Toolkit of Management Actions

While capacity building, primarily research and extension, are the logical initial focus of climate impacts and adaptation efforts for biodiversity management, there is a need to proactively identify, develop and test potential implementation actions. To date, there is no consolidated handbook of proven biodiversity conservation techniques, or climate adaptation techniques, that are targeted to BC. Consideration should be given toward developing a compendium of biodiversity and climate change case studies from around the world, and building local case studies through targeted investments. Over time further consideration should be given to developing BC's own 'how to" manual, perhaps modeled after the one published by the World Wildlife Fund (see Hansen *et al*, 2003).

Develop a Strategic Approach to Impact and Adaptation Options Assessment

It is beyond the scope of this report to develop detailed assessments for each of the priority climate change threats to biodiversity shown in Table 2. However we can begin by outlining the steps for a strategic approach to the task. Theses steps include:

1. Defining biodiversity management priorities in terms of the specific endpoint at risk for each system (i.e., ecosystem, species or genetic diversity).
2. Identifying the climate stressors, and developing future scenario projections for the climate variables of interest.
3. Identifying the impact mechanisms and documenting potential future impacts and uncertainties.
4. Developing a set of feasible adaptation actions.
5. Collecting information on the costs and benefits of adaptation options.

6. Conclusion

Climate change – including changes in long-term average conditions, variability or the frequency or severity of extreme events – will affect biodiversity from genes to species to ecosystems. In BC, past changes in climate have been recorded, and future projections are available that can provide a starting point for assessing the types of climate stressors that will impact various biodiversity management endpoints in our terrestrial and freshwater systems.

The government of BC lays out the following three key policy objectives to be met in its current climate change plan (BC WLAP, 2004):

Risk Management – decrease GHG emissions to reduce BC's contribution to global climate change,

Economic Revitalization – Support economic revitalization by improving energy efficiency and supporting business innovation,

Federal Engagement – ensure BC's interests are protected in the implementation of national climate change policies.

Noticeably absent is an <u>explicit</u> objective related to environmental protection in general, or biodiversity conservation in particular. Given the scope of potential impacts in BC, we strongly believe that a stated objective for biodiversity conservation should be included as part of any update to BC's climate change plan.

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