# Implications of Climate Change in British Columbia's Southern Interior Forests

April 26–27, 2005
Revelstoke, British Columbia
Canada

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## Acknowledgements

The Columbia Mountains Institute of Applied Ecology is proud to have worked with the following partners to host this workshop.

**B.C. Ministry of Water, Land and Air Protection**
Water, Air and Climate Change Branch
http://wlapwww.gov.bc.ca/air/climate/index.html
Jenny Fraser
Phone: 250-953-3812 Email: jenny.fraser@gov.bc.ca

The Water, Air and Climate Change Branch develops legislation and policies to protect air quality, water quality, and the land. On behalf of the Province of British Columbia, the branch coordinates implementation of a provincial strategy to address global climate change.

**Canadian Climate Impacts and Adaptation Research Network**
Greg McKinnon, Forest Sector
http://forest.c-ciarn.ca

The mission of the Canadian Climate Impacts and Adaptation Research Network is to build a network of researchers and stakeholders who will help develop credible information on the impacts of climate change in Canada and help identify adaptation options, to anticipate and prepare for changes that are expected during the 21st century.

This workshop received additional financial and in-kind support from these agencies:

- B.C. Ministry of Water, Land and Air Protection
- B.C. Ministry of Forests
- Canadian Climate Impacts and Adaptation Research Network
- Canadian Institute for Climate Studies
- Canadian Forest Service
- Downie Timber
- Environment Canada
- Parks Canada
- Pope and Talbot
- Revelstoke Community Forest Corporation
- Revelstoke Credit Union
- Royal British Columbia Museum
- Tembec Forest Industries
- University of British Columbia
- US Geological Survey, Northern Rocky Mountain Science Centre.

## *Special Thanks!*

Special thanks are due to our **volunteers,** who assisted with taking notes at the workshop, and with the many details that keep the event running smoothly on April 26 and 27. Their records of the presentations and the breakout groups add to the quality of this document.

- Marissa Main, Castlegar, British Columbia
- Lindsay McBlane, Burnaby, British Columbia
- Patricia Perkins, Victoria, British Columbia
- Alice Weber, Revelstoke, British Columbia

The following people kindly agreed to be **facilitators** for the four Wednesday afternoon working groups:

- Jenny Fraser, Ministry of Water, Land and Air Protection
- Bill Taylor, Environment Canada
- Dave Spittlehouse, B.C. Ministry of Forests
- Robin Sydneysmith, Canadian Climate Impacts and Adaptation Research Network

Our **presenters** travelled from Montana, Ottawa, Vancouver, Victoria, and the Kootenays to share their expertise with us. We are grateful for their participation and for the support of their host agencies; many of them covered time to prepare and present the talks, and costs for travelling to Revelstoke.

Our **Master of Ceremonies** was Patrick Daigle, from the Biodiversity Branch of the Ministry of Water, Land and Air Protection. Patrick was Chair of the Organizing Committee for this event, and we are grateful for his willingness to take on this role. Patrick is also a Director of the Columbia Mountains Institute of Applied Ecology.

And, of course, we'd like to thank the **workshop participants**, who travelled from various towns in British Columbia, Alberta, and Montana to attend the workshop.

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*continued…*

# Workshop Description

In its 2001 assessment, The United Nations-sponsored Intergovernmental Panel on Climate Change (IPCC) concluded that global atmospheric temperature rose by 0.6ºC during the 20th century, and that most of this warming can be attributed to human activities that release greenhouse gases into the atmosphere, including land clearing and the burning of fossil fuels. Atmospheric warming drives changes in other aspects of the climate system, including regional precipitation, evaporation, cloud cover, and the frequency of extreme weather events. Changes in regional climate are greatest at mid- to high latitudes and interior, rather than maritime, locations. The IPCC concluded that during the 21st century global mean temperature will warm by 1.4 to 5.8ºC. This is a rate of warming likely faster than at any other time during the past 10,000 years.

The composition, health, and vitality of British Columbia's southern interior forests are strongly linked to regional climate and climate variability. Changes in regional climate will drive changes (not necessarily increases) in the frequency and/or severity of climate-associated effects such as drought, wildfire, and outbreaks of insects and diseases, which are already concerns in southern British Columbia. In turn, forest productivity, ecosystem functioning, and habitat values will be affected, in many cases adversely, but sometimes positively.

Given the threats and opportunities imposed by climate change and the potential vulnerability of British Columbia's southern interior forests, it is prudent that forest and protected area managers begin to develop adaptive strategies to minimize the risks and maximize any benefits of climate change. Although natural systems will adapt autonomously to a changing climate, proactive planning and management offers the potential to avoid many adverse outcomes on the environmental, social, and economic systems that are tied to the historic and current composition and structure of southern interior forests.

At this workshop, participants heard what climate models have to say about the future regional climate and also heard about potential implications for flora, fauna, and ecosystems. On the second day, participants were shown how to begin planning for the effects of climate change. Breakout sessions provided an opportunity to test new understandings on case studies of a protected area and a managed forest.

The workshop was attended by 115 people plus two senior classes from Revelstoke Secondary School, who dropped in for parts of the event. The occupations of the participants included forestry professionals and technicians, biologists, ecologists, protected-area managers, educators, college and university students, representatives of non-profit groups, and others with an interest in how climate change may affect forest ecosystems.

## Workshop Agenda

*Tuesday April 26, 2005*

| | |
|---|---|
| 8:45 am | **Opening Remarks and Welcome from Revelstoke Mayor Mark McKee**<br>Patrick Daigle, Director, Columbia Mountains Institute<br>Mark McKee, City of Revelstoke |
| 9:00 | **Climate Change and Variability**<br>Bill Taylor, Environment Canada |
| 9:30 | **Climate Model Scenarios Prepared for Workshop Case Studies**<br>Trevor Murdock, Canadian Institute of Climate Studies |
| 10:00 | Coffee Break |
| 10:20 | **The Future of Tree and Forest Distribution: Lessons from Paleoecology and Climate Change Models**<br>Richard Hebda, Royal British Columbia Museum |
| 10:50 | **Potential Effects of Climate Change on Ecosystem and Tree Species Distribution in British Columbia**<br>Andreas Hamann, University of British Columbia |
| 11:20 | **Climate Change and Forest Fire in British Columbia**<br>Brad Hawkes, Canadian Forestry Service |
| 12:00 p.m. | Lunch (provided) |
| 1:00 | **CMI Annual General Meeting** |
| 1:30 | **Climate Change and Mountain Pine Beetle**<br>Brad Hawkes (for Allan Carroll), Canadian Forestry Service |
| 2:00 | **Climate Change Adaptation for Park Managers**<br>David Welch, Parks Canada |
| 2:30 | **Climate Change and Biodiversity—A Global Perspective**<br>Lee Harding, SciWrite Environmental Services Ltd. |
| 3:10 | Coffee Break |
| 3:30 | **Towards a General Model of Avian Response to Climate Change**<br>Fred Bunnell, University of British Columbia |

4:00 **Mountain Caribou and Climate Change**
Greg Utzig, Kutenai Nature Investigations

4:30 **Understanding and Predicting the Effects of Climate Change on Mountain Forest Ecosystems: The CLIMET Project**
Dan Fagre, US Geological Survey

5:00 Social Hour

*Wednesday April 27, 2005*

9:00 a.m. **Visualizing Climate Change Scenarios**
Ross Benton, Canadian Forestry Service

9:30 **More Climate Information**
Trevor Murdock, Canadian Institute for Climate Studies

10:00 **Adaptation to Climate Change in Forest Management: Challenges and Responses**
Dave Spittlehouse, B.C. Ministry of Forests

10:30 Coffee Break

10:45 **Climate Change and Forest Policy in British Columbia: Challenges and Opportunities**
Dale Draper, B.C. Ministry of Forests

11:15 **An Adaptation Planning Framework for Forest Management**
Greg McKinnon, Canadian Climate Impacts and Adaptation Network

12:00 Lunch (provided)

1:00 **Breakout Groups**

3:00 **Reporting Back** from Breakout Groups, Plenary Discussion

4:00 **Closing Comments** and Adjournment, Patrick Daigle

# Presentation Summaries

## About the Presentation Summaries

The summaries that follow are a combination of information provided by authors at the conference, as well as notes taken during presentations. Several speakers were reporting on work published elsewhere and have provided an abstract plus references for more information. Contact information is provided for all presenters, along with the invitation to contact the presenters directly for more details about their work.

## 1. Climate Change and Variability

Bill Taylor
Senior Scientist, Atmospheric Issues, Environment Canada, Vancouver
Phone: 604-664-9193   Email: bill.taylor@ec.gc.ca

***Abstract***

Climate stations within British Columbia have been analyzed for the 1950 to 2002 period for seasonal and annual trends and to determine inter-annual and inter-decadal climate variability. Temperatures throughout British Columbia have risen over the latter half of the 20$^{th}$ century, with overnight lows showing a greater rate of increase than daytime highs. Spring and winter are the seasons of greatest temperature change. Precipitation patterns have also changed. Much of British Columbia has experienced decreasing trends in winter precipitation since 1950, while spring and summer precipitation has increased during that period. Some of these changes may be attributed to natural swings in the climate due to El Niño and the Pacific Decadal Oscillation. Notwithstanding these natural variations, there remains a warming trend consistent with a more widespread change in global climate. The warming trend is projected to persist into the future with the continued rise in global concentrations of greenhouse gases. A particularly troubling aspect of this trend is the accelerated pace of warming that is predicted to occur. The effects of climate change on forestry, agriculture, fisheries, and other resource-based sectors in British Columbia could be considerable.

***Global Temperature Trends***

According to the Intergovernmental Panel on Climate Change (IPCC), there was an overall warming of the planet of $0.6 \pm 0.2$ ºC during the 20$^{th}$ century (Houghton *et al*. 2001). Recent studies from the University of Texas have shown that this slight increase in temperature has had a dramatic effect on plant phenology (e.g., flowering dates), the timing of animal breeding behaviours, bird nesting, egg hatching, and migration dates. The temperature increase has also caused some species to shift their range northward by several kilometres (Parmesan and Yohe 2003).

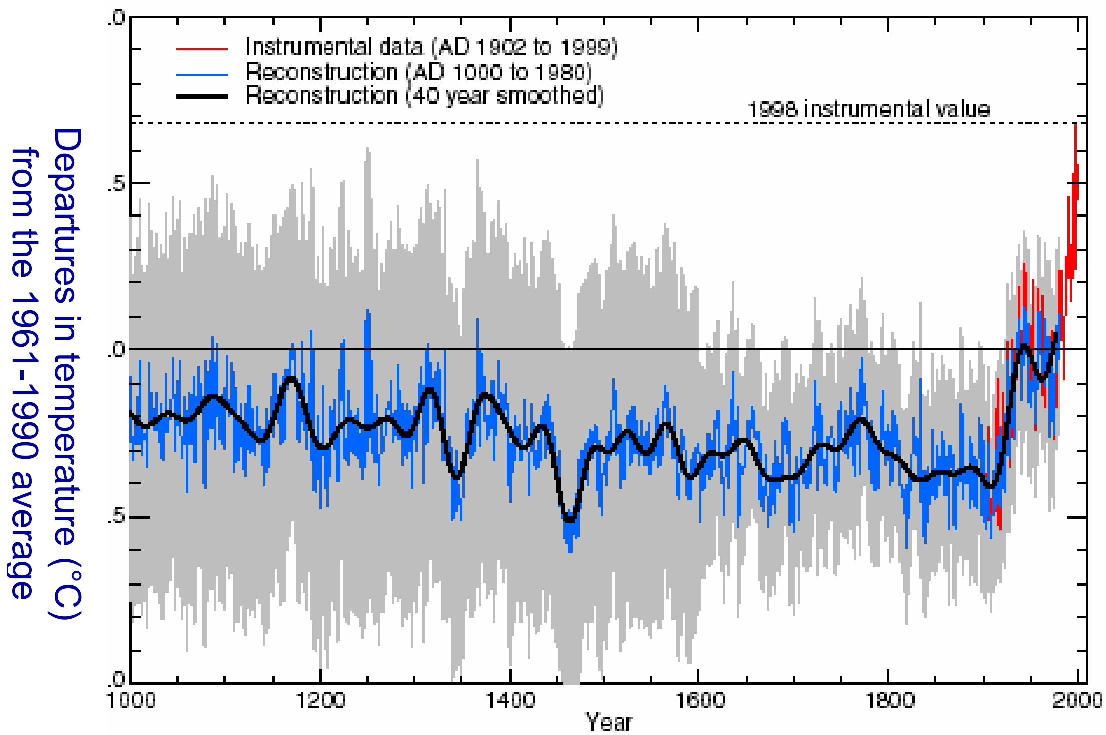


**Figure 1.** Variations in the Earth's surface temperature for the past 1000 years (Northern Hemisphere). Source: IPCC 2001.

To determine whether the warming of the 20th century was unusual, scientists used proxy data over the past 1,000 years based on temperature reconstruction from ice cores and from coral and tree rings (Figure 1). Global temperatures remained stable over the first 900 years of the millennium, and if anything, showed a slight cooling during this period. However, at around the beginning of the 20th century, there was a sharp rise in temperatures giving the resulting time series the shape of a hockey stick (Mann *et al*. 1999). There were two distinct periods of warming during the 20th century: 1910 to 1940, and the mid-1970s to 2000. The period between 1940 and 1975 was characterized by a slight cooling. Uncertainties in temperature measurements during this time arise, however, from data gaps, random instrumental errors, changes in the amount of global coverage, and adjustments for urbanization. Recently, the methods used to create this reconstruction have been called into question (McIntyre and McKitrick 2005), and it is expected that the IPCC will have to reassess these results in its next science assessment due in 2007.

### *Climate Trends in Canada*

Efforts to detect temperature trends for the entire country of Canada are hampered by the fact that the observational network was not established in the north until the late 1940s. Consequently, climate trends over the whole of the 20th century have been calculated only for southern Canada. During this period, temperatures rose 0.9ºC in southern Canada, although the linear trend was not monotonic. Similar to the global pattern, two periods of warming were evident—prior to the 1940s and after the 1970s and a slight cooling occurred between 1940 and 1970 (Zhang *et al*. 2000).

There are large regional and seasonal differences in the rate and character of climate change in Canada. Trends for the latter half of the 20th century have been calculated for all of Canada. The most obvious feature of the regional temperature pattern is that while much of western Canada warmed during the last 50 years of the 20th century, the northeastern region of Canada along the Labrador Sea actually cooled (Figure 2). This regional pattern of warming in the south and west, and cooling in the northeast, is consistent with decadal scale changes in ocean circulation such as the North Atlantic Oscillation and the Pacific Decadal Oscillation.

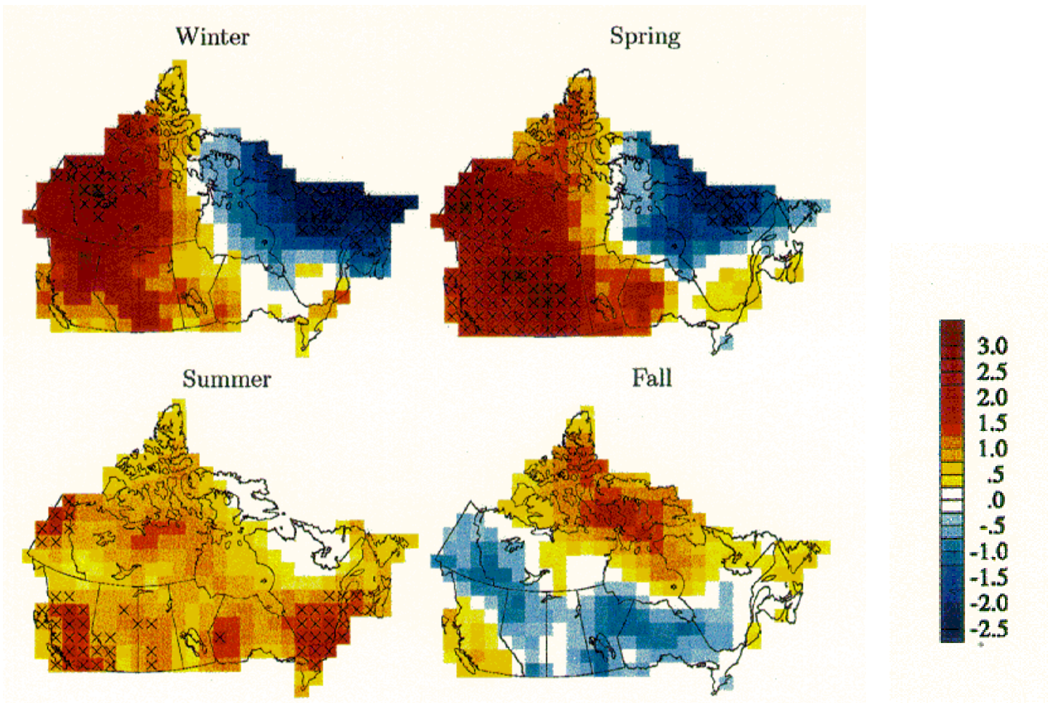


**Figure 2.** Trends in daily minimum temperature for Canada from 1950 to 1998. Source: Zhang *et al*. 2000.

There was also considerable variation in seasonal climate patterns in Canada during the last half of the 20th century. Spring was the season of greatest warming in southern and western Canada, although winter temperatures also showed large increases. In the northeast, winter and spring were the seasons of greatest cooling. Summer temperatures rose fairly uniformly across the country, and trends are statistically significant throughout much of British Columbia. Autumn temperatures decreased in most parts of the country except British Columbia and the north.

Canada is not getting warmer, just "less cold" because most of the increase has been due to a rise in night-time minimum temperatures, and the greatest warming has occurred during the coldest half of the year (Zhang *et al*. 2000). Annual precipitation has also increased, although springtime snowfall has decreased in western Canada, which corresponds to the rise in spring temperatures.

*Climate Trends in British Columbia*

Daily minimum temperatures rose more than daily maximums in British Columbia between 1950 and 2002, and the interior of the province warmed more than coastal regions (Figure 3). Winter and spring show the largest warming trends. While summer trends are typically smaller, they are often more statistically significant because inter-annual variability is lower during that season as compared to winter and spring. Increases in mean annual temperature range from 0.5°C along the coast to 2.5°C in the northeastern part of the province.

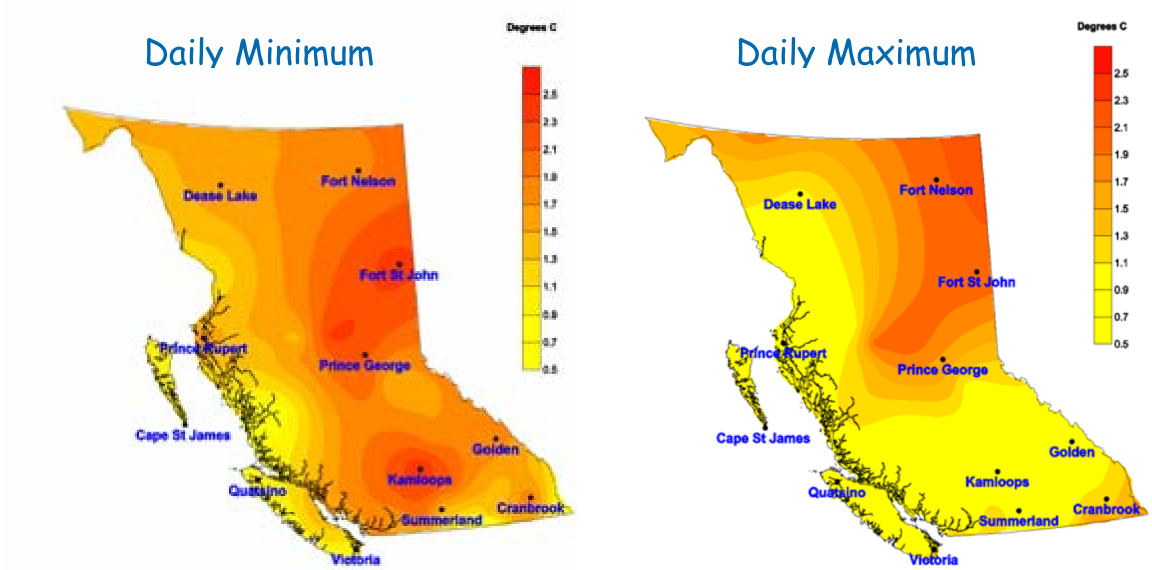


**Figure 3.** Trends in annual average of daily minimum and maximum temperatures for British Columbia from 1950–2002.

In southern British Columbia, precipitation increased during spring and summer between 1950 and 2002 by as much as 35–40% (Figure 4, next page). Winters have become drier over the same period throughout much of the province, except along the north and central coastal region, which has become wetter. Mean annual precipitation has increased in British Columbia over the latter half of the 20th century, although these trends are generally not statistically significant.

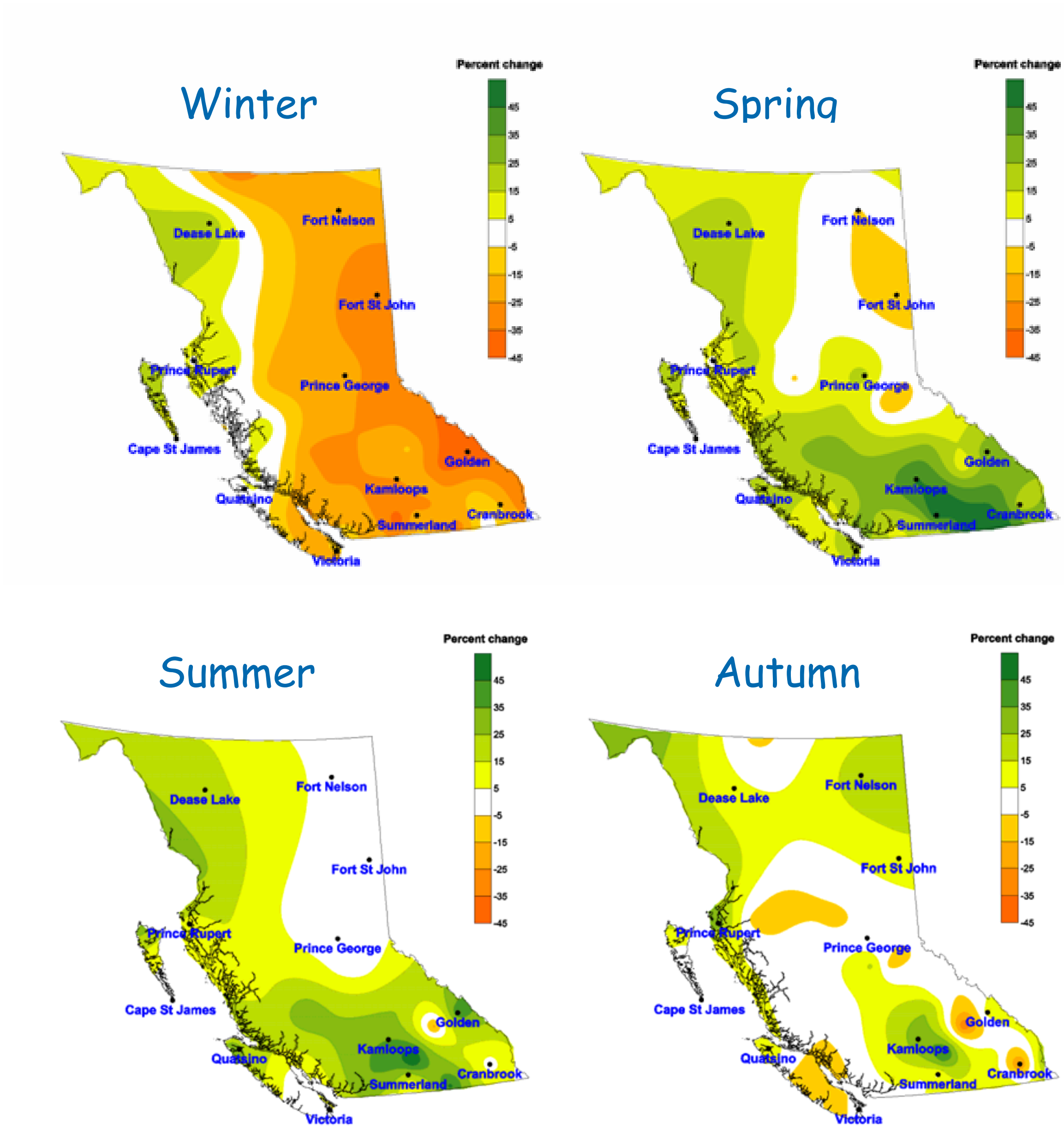


**Figure 4.** Trends in seasonal precipitation in British Columbia from 1950–2002.

***Natural Climate Variability***

There is little doubt that the earth's climate is changing, and according to the IPCC, most of the warming of the past 50 years may be attributed to human activities (Houghton *et al*. 2001). However, climate has its own natural rhythm, which explains at least some of the variability in temperature and precipitation on inter-annual and inter-decadal time scales. For reasons that are not well understood, the periodic warming and cooling of the tropical Pacific Ocean that we know as El Niño/Southern Oscillation (ENSO) exerts an influence on the position of the storm track and circulation patterns over North America (Wallace and Gutzler 1989). During El Niño, the Aleutian Low (a semi-permanent, low-pressure centre in the North Pacific) deepens, resulting in a more southerly flow of mild Pacific air, higher freezing levels, and reduced snow fraction. Temperatures throughout western Canada are reliably higher during El Niño winters, and are typically lower during the opposite phase, La Niña (Shabbar and Khandekar 1996).

On longer time scales, the Pacific Decadal Oscillation (PDO) has a similar influence on the climate as El Niño (Mantua *et al*. 1997; Trenberth and Hurrell 1994; Trenberth 1990). However, in contrast to El Niño, which occurs in the tropical Pacific, the action centre of the PDO is in the North Pacific, and it persists in one phase or the other for many years running. A change in phase of the PDO in 1976 is well documented, and coincides with the beginning of the long-term decline in low elevation snowpacks in southern British Columbia (Moore 1996; Moore and McKendry 1996).

### *Future Climate Change*

The future climate cannot be known with a high degree of confidence for a variety of reasons, beginning with large uncertainties in forecasting future greenhouse gas emissions. The IPCC has constructed scenarios that broadly characterize the different paths global society could follow over the next 100 years in terms of three important parameters: population, economic growth, and technological change (Nakićenović *et al*. 2001). The IPCC published these scenarios in its *Special Report on Emissions Scenarios* (SRES). Storylines were developed for each of six marker scenarios that describe the world of the future in terms of population, economic development, and technological change. These marker scenarios are referred to as A1, A2, B2, and so on.

High emission scenarios, such as A1 and A2, result from assumptions of accelerated population growth and rapid economic development with possible continued reliance on fossil fuels. Low emission scenarios are based on lower rates of population growth, slower rates of economic development, and greater use of alternative fuels. Each of these emission scenarios results in a different rate of accumulation of greenhouse gases in the atmosphere throughout the 21$^{st}$ century.

Global climate models were then run using these emission scenarios to determine the climate response to different greenhouse gas forcing. Higher emission scenarios result in the greatest warming, whereas lower emission scenarios produce a more moderate temperature response. Based on the full range of SRES scenarios, the IPCC predicts global temperature increases in the range of 1.4–5.8 ºC by the end of the 21$^{st}$ century (Houghton *et al*. 2001). A warming of this magnitude would be unprecedented in the past 10,000 years, and is well outside any climate we have experienced. To put this warming into perspective, the temperature at the peak of the last ice age was only about 6ºC cooler than today's. The warming expected over the next 100 years is of roughly the same magnitude as the warming that has occurred since the last glacial maximum.

An incomplete understanding of the climate system, combined with uncertainties in accurately forecasting future socio-economic conditions, limits our ability to predict the future climate with any confidence. Uncertainties cascade throughout the entire climate change impacts-assessment process beginning with the emission scenarios, then with estimating the concentrations associated with those emissions, followed by modelling the climate forcing resulting from the increase in concentrations, and so on down to variations in the regional response to this global forcing and their ultimate impacts. Despite these uncertainties, "the overwhelming majority of scientific experts, whilst recognizing that scientific uncertainties exist, nonetheless believe that human-induced climate change is inevitable. The question is not whether climate will change, but rather how much, how fast, and where." (Houghton *et al*. 2001)

### *The Case for Adaptation*

Under the Kyoto Protocol, the developed countries of the world have set individual targets for reducing greenhouse gas emissions, which collectively amount to a reduction of 5.2% from 1990 levels by 2008–2012. This modest reduction will slow, but not stop, the buildup of greenhouse gases in the atmosphere. Stabilization of concentrations of greenhouse gases in the atmosphere would require reductions in emissions to a small fraction of current levels. Even if greenhouse gas concentrations are stabilized by the end of the 21st century, global temperatures will continue to rise until a new climatic equilibrium is reached. Sea levels will continue to rise for several more centuries because of the huge thermal inertia of the oceans (Houghton *et al*. 2001).

So, while greenhouse gas mitigation is an important strategy in reducing the impacts of global climate change, some degree of either natural or planned adaptation to new climatic conditions will be required. Some adaptation, particularly in natural ecosystems, will be autonomous. In human systems, there is the opportunity for planned adaptation, which results from a deliberate decision based on an awareness that climate conditions have changed, or are about to change.

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***Web Site:***
Intergovernmental Panel on Climate Change
www.ipcc.ch/

***Questions after Bill's Presentation:***

Question:

Delay period between $CO_2$ emissions and climate change—climate change now is based on 1960s emission—can you speak to that?

Response:

- Climate is not in equilibrium; energy is entering the climate system at a greater rate than it is being returned to space resulting in climate warming.
- If we could stabilize greenhouse gas emissions today, there would still be a delay of decades before a new climate equilibrium is reached.

Question:

What's the mechanism?

Response:

- Adjustments in the radiative balance between incoming and outgoing radiation occurs slowly because of the large thermal inertia (heat capacity) of the oceans

Richard Hebda with additional comment:

- Warming of atmosphere as well as ocean
- $CO_2$ in atmosphere traps heat and re-radiates it
- Continues until $CO_2$ molecule goes into ocean or tree, etc.
- Like a freight train, it keeps on moving

Question:

Is there truth to the possible shut down of the thermohaline circulation?

Response:

- Bill explains "conveyor belt" system briefly

- Shutting down the Gulf Stream would throw Europe into deep freeze
- Rather a remote possibility
- Other things are more visible now (today)
- Not ideal to wait for cataclysmic event before taking action

Question:

What's the role of sun in climate change?

Response:

- Solar output is not constant
- Compared to action of $CO_2$ it's a small effect

## 2. Climate Model Scenarios for Workshop Case Studies

Trevor Murdock
Canadian Institute for Climate Studies, Victoria
Phone: 250-472-4681 Email: tmurdock@uvic.ca Web site: www.cics.uvic.ca

*** Trevor's complete PowerPoint presentation is available online at www.cics.uvic.ca/scenarios/index.cgi?Workshops

***Abstract***

This talk set the context for use of climate scenarios and presented an overview of the basic climate change scenarios for the region. Background information about climate scenarios included information about climate variability, climate change, global climate models, construction of regional climate scenarios, and sources of uncertainty.

***Acknowledgements***

*Content:* Jenny Fraser, Johanna Wolf, Jackie Morris, Rick Lee, Andreas Hamann, Daniel Caya, and Greg McKinnon
*Financial Support:* B.C. Ministry of Water, Land and Air Protection; University of Victoria

***About the Canadian Institute for Climate Studies (CICS)***

CICS was founded in 1993 by the Province of British Columbia and Environment Canada at the University of Victoria to "further the understanding of the climate system, its variability and potential for change, and to further the application of that understanding to decision making in both the public and private sectors." CICS has engaged in several main areas of work since 1993, including:

- Climate Research Network
- Seasonal climate predictions
- Climate applications
- Climate scenarios
- Science-based policy

CICS is currently pursuing a regional focus in partnership with the Province of British Columbia.

***Climate Variability and Climate Change***

Climate variability is related to strength, interaction, and frequency of preferred atmospheric circulations, such as El Niño/Southern Oscillation, Pacific Decadal Oscillation, North Atlantic Oscillation, and the Arctic Oscillation. It takes place on a scale of years to decades, and can be thought of as rises and falls on a long-term trendline. Climate change then is measured as long-term trends on the scale of centuries. Climate variability is ongoing, which means that 30-year "normals" change. There is an obligation for us to plan for climate variability since our plans, infrastructure, and expectations are based on a very short period of climate record.

Climate variability is predictable with some precision. For example, our seasonal climate predictions for British Columbia's Okanagan over 6 years are 44% correct (28% with historical averages; three-category season). CICS's seasonal climate predictions called for the recently experienced warm winter weather since July 2004 and warm spring weather since September 2004.

To effectively study climate change, we recommend starting by identifying vulnerabilities— extreme winter cold for pine beetle, spring and summer drought, summer temperature for fires, etc. then studying potential impacts by using projections of future climate. A range of scenarios from Global Climate Models are used to deal with uncertainty. Downscaling and Regional Climate Models (RCMs) are used for regional results. Finally, adaptation strategies may be developed manage for current and potential future climate impacts of both climate change and variability.

### *Global Climate Models and Uncertainty*

Global Climate Models (GCMs) are complex computer models that simulate weather patterns. Uncertainty arises from:

- not knowing future population, energy consumption, and thus levels of greenhouse gas (GHG) emissions;
- uncertainties in how carbon cycle dynamics will convert GHG emissions into GHG concentrations (which is what drives climate);
- different parameterizations in the physics, bio-chemistry, and dynamics of the GCMs themselves;
- techniques to bring results to a regional scale such as downscaling and regional climate models; and
- application of GCM results to impacts models with their own inherent uncertainties.

### *Scenarios*

Scenarios are used in order to incorporate uncertainty by presenting a range of results rather than a "best prediction." The CICS Scenarios web site is available at www.cics.uvic.ca/scenarios/ and includes several flexible options, including custom regions, dynamic map creation, scatterplots and other tools, and background information. Regional Climate Model data and high resolution baseline data will be added shortly.

At the workshop, scatterplots were presented and explained for several seasons and several parameters. General results were presented; for example, the 20-year return period level of precipitation is projected to occur more often, with a return period of 8–13 years (for North America as a whole, based on two scenarios from the Canadian GCM, 2000 return period compared to 2090). Examples of scatterplots (scenarios from all models and emission scenarios) for winter temperature and precipitation are shown below:

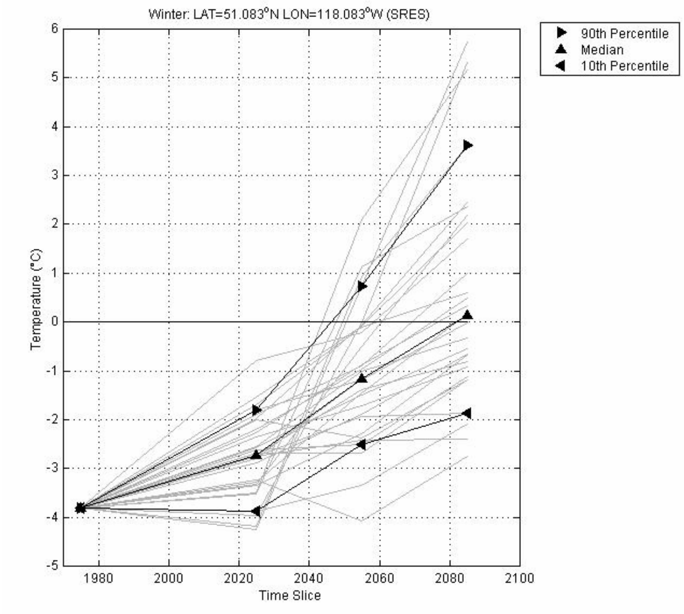


**Figure 1.**
Winter temperature at Revelstoke:

- 1961–1990: -3.8ºC
- 2050s: -2.5 to 0.7ºC

**1.3 to 4.5ºC increase**

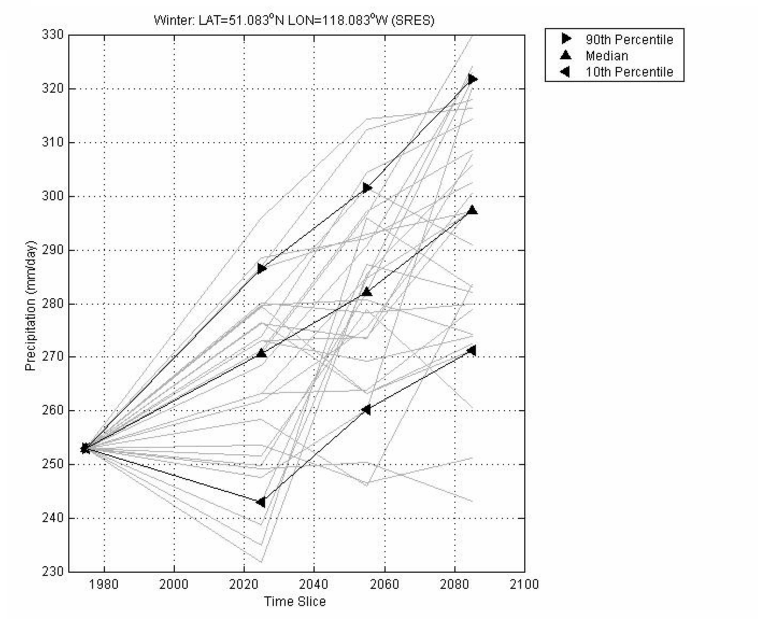


**Figure 2.**
Winter precipitation
at Revelstoke:

- 1961–1990: 253 mm
- 2050s: 260 to 302 mm

**3 to 19% increase**

***Questions after Trevor's Presentation:***

Question:

If modelling is based on only 30 years of data and natural variability plays a role, how can we base models on that data?

Response:

- Not really based on only 30 years of data—the use of 30 years to is to express a change; it's how the "normals" are calculated. Thirty years is considered a climate normal period.
- Normals are used as something to compare to, not something to derive from.
- Use as much data as possible—generally 100 years of data.
- If you have long records, you are more likely to get statistically significant values; if using a shorter record you must be extremely careful.

Question:

If red on maps in the British Columbia climate models are major shifts, why wouldn't red creep up into the Okanagan?

Response:

- You saw the red shift on the coast in the Climate BC projections. This is an artifact of the spatial averaging used in this version of the model, which currently results in a warm bias on the coast.
- You would actually see smaller changes on the coast than the model suggested; in fact we would expect less warming on the coast than in the interior.

*For more information on climate trends and predictions*
*for southern British Columbia,*
*please refer to Appendix Six of this document.*

## 3. The Future of Tree and Forest Distribution: Lessons from Paleoecology and Climate Change Models

Richard Hebda
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The study of tree and forest distributions from fossil pollen in lake and bog sediments in combination with models of future species distributions using bioclimate profiles (climatic envelopes) provides a powerful tool for assessing potential consequences of climate change.

Before 4000 years ago climates were generally warmer in British Columbia, and tree distribution and forest composition and structure differed from the present. A warm and dry climate 7000-10,000 years ago fostered widespread non-forest ecosystems particularly in southern British Columbia. Moisture-favouring species and forest types such as those including western hemlock and western red cedar were of limited extent, and forests with no real modern analogue occurred.

Climate change modelling of western red cedar distribution strongly suggests a return to conditions similar to those in the past, with signs of change already evident and the rate of change intensifying in the next decade. Widespread and major changes in forest species distribution and forest composition and structure must be expected in the next few decades.

A key challenge will be the phenomenon of the "big squeeze' whereby climatically mediated decline in species ranges will be much more rapid than natural expansion into newly available areas.

***A few phrases from Richard's presentation –***

"When the climate changes, everything changes. *Climate rules*."

"When we talk about how a changing climate affects forests, there are many things we don't understand because we don't have enough field ecologists. *Time for Boots and Suits, not just Suits."*

"Ecosystems don't migrate; species do. Plants may be able to survive in a new area, but somehow they have to get there. How does this happen if they are dying in their current range?"

"Soil an important integrator of things over time – we really don't know how hydrology, forests, etc. interact, but soil brings things together."

### ***Questions after Richard's Presentation***

Question:

With tree species, we may have tree seeds that we can plant to ameliorate some of the problems. What about other plants? Do we have the resources?

Response:

This is complicated. We know about commercial and charismatic species, but we need to know more about other species and we need to know about the interrelations between species. Not just pests, but more complex connections such as mycorrhizae, role of nurse plants, etc. Soil is so very important for bringing things together.

Comment:

Disturbance due to climate change (e.g., large fires or insect outbreaks) may cause things to change more quickly than we think. When we take out all of the forest due to MPB, perhaps it won't re-establish if the conditions are warmer. Say goodbye to Chilcotin trees because they may not re-establish (grassland?).

## 4. Potential Effects of Climate Change on Ecosystem and Tree Species Distribution in British Columbia

Andreas Hamann presented this information.
Centre for Forest Gene Conservation
Phone: 604-822-1845 Email: hamann@interchange.ubc.ca

Andreas Hamann [1], Tongli Wang [1], Sally Aitken [1], Dave Spittlehouse [2], Alvin Yanchuk [2]
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A new ecosystem-based, climate-envelope modelling approach is applied to assess potential climate change impacts on forest communities and tree species. Four orthogonal canonical discriminant functions are used to describe the realized climate space for British Columbia's ecosystems and to model the realized niche space for tree species under current and predicted future climates. This conceptually simple model is capable of predicting species ranges at high resolution far beyond the study area, including outlying populations and southern range limits for many species. We analyze how the realized climate space of current ecosystems changes in extent, elevation, and spatial distribution under climate change scenarios and evaluate the implications for potential tree species habitat.

Tree species with their northern range limit in British Columbia gain potential habitat at a pace of at least 100 km per decade; frequent hardwoods appear to be generally unaffected by climate change and some of the most important conifer species in British Columbia are expected to lose a large portion of their suitable habitat. Despite the fact that response to climate change is not modelled separately for each species, species do not change their distribution or frequency in concert as expected from niche theory. The results support the theoretical expectation that in community-wide surveys of biological response to climate change a certain proportion of species will show none or a reversed response. The predicted spatial re-distribution of realized climate space for British Columbia's ecosystems appears to be considerable even at the zone level, which represents major forest types. Ecosystems in mountainous areas appear to be particularly vulnerable, spatially shifting out of their current climatic envelope within 50 years.

Other notable predictions are the initial expansion of the climatic envelope for the Interior-Cedar-Hemlock climate regionwithin approximately 25 years, followed by expansion of the Interior Douglas-fir and Ponderosa Pine climate regions throughout the interior plateau, replacing the current climate space of sub-boreal and boreal ecosystems. The magnitude of predicted changes, climate change trends already observed in British Columbia, and presumed biological impacts, such as the current mountain pine beetle epidemic, strongly suggest that ecosystems and forest resources are threatened by continued global warming. If currently observed climate trends continue or accelerate, major changes to natural resource management practices will become necessary. Because of modelling uncertainties at small spatial scales, systematic monitoring of biological response to locally observed climate trends may be the best guide for the implementation of management changes. Predictions of expected community-wide biological response based on observed changes in climate can be used to support or reject the hypothesis that observed biological changes are causally related to climate trends.

*The following reprints and manuscripts are available from the authors:*

Hamann, A. and Wang, T. 2005. Models of climatic normals for genecology and climate change studies in British Columbia. Agric. For. Meteorol. 128:211–221.

Wang, T., A. Hamann, D. L. Spittlehouse, and S. N. Aitken. 2005. Development of scale-free climate data for western Canada for use in resource management. (mansucript submitted).

Hamann, A. and Wang, T. 2005. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. (manuscript submitted)

*Excellent information is available through Andreas' web site:*

http://genetics.forestry.ubc.ca/hamann/

# 5. Climate Change and Forest Fire in British Columbia

Brad Hawkes presented this information.
Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre
Victoria, British Columbia
Phone: 250-363-0665 Email: bhawkes@pfc.cfs.nrcan.gc.ca

Mike Flannigan, Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, Ontario.
Bernie Todd, Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Alberta.

***Abstract***

Climate change will result in an altered fire regime. Understanding the changes in fire activity, number of fire starts, fire behaviour, and area burned that British Columbia can expect under climate change is extremely important from a biodiversity, timber supply, and community protection standpoint. Weather projections for western Canada, as modelled by the Canadian Regional Climate Model (RCM), were modified for British Columbia by applying elevation-correction routines to the 45-km grid cell RCM data. As well, spatial relationships were developed to transpose the RCM data from a non-spatial to a spatial structure at 5-km resolution. For each of three scenario periods, 1 x $CO_2$ (1975–1985), 2 x $CO_2$ (2040–2049) and 3 x $CO_2$ (2080–2089), daily weather and Fire Weather Index (FWI) maps were created. Current and future fire weather and danger scenarios for British Columbia were examined to better understand the potential changes in fire severity and danger and length of fire season over time.

***Introduction***

A collaborative research agreement between the Protection Program of British Columbia's Ministry of Forests (MOF), and the Northern Forestry Centre of Canadian Forest Service (CFS), Natural Resources Canada, was developed in July 2000 to facilitate the assessment of past, current, and future fire occurrence and fire severity in British Columbia to determine the potential impact of climate change. The CFS project team members were Mike Flannigan, Brian Stocks, Mike Wotton, Bernie Todd, Heather Cameron, and Kimberley Logan. A project report was submitted to the Protection Program in 2002 (Flannigan *et al*. 2002). The project contacts were Judi Beck and John Flanagan.

Fire activity is strongly influenced by four factors: weather/climate, fuels, ignition agents, and humans (Johnson 1992; Swetnam,1993; Flannigan and Wotton 2001). Climate and the associated weather are dynamic and always changing due to changes in the earth's orbital parameters, solar output, and atmospheric composition. Recently, our climate has been warming due to increases of radiatively active gases (carbon dioxide, methane, etc.) as a result of human activities (IPCC 2001). This altered climate, which is modelled by Global Climate Models (GCMs), may have a profound impact on fire activity in Canada and elsewhere in the near future. Climate change will result in an altered fire regime, which has the potential to have more impact than the direct effects of climate warming on forest species distribution, migration, substitution, and extinction (Weber and Flannigan 1997). Understanding the changes in fire activity—namely, number of fire starts, length of fire season, fire behaviour, and area burned—that British Columbia can expect under climate change is also extremely important to the general public from a timber loss and community protection standpoint.

Typically, global climate change is modelled through the use of GCMs. These modelled simulations of future climate, which include the effects of increasing levels of $CO_2$ in the atmosphere, indicate that global surface air temperatures could increase approximately 1.4– 5.8$^{o}$C over the next century (IPCC 2001), with a stronger increase expected in the mid- to high latitudes. For the boreal forest area of Canada, the Canadian Climate Centre GCM predicts increases of 3–6$^{o}$C in surface air temperatures by the end of the current century (Flannigan *et al*. 2001). However the resolution of the GCM is inadequate to reliably predict events for British Columbia, and more sophisticated analysis is required to predict the impact of climate change for British Columbia's complex terrain and vegetation conditions at a regional level. The Canadian RCM uses the output from the Canadian GCM to generate information at a finer spatial and temporal scale that is at six-hour intervals and a 45-km resolution. The three time slices used for this simulation are 1975–1985, 2040–2049, and 2080–2089; and correspond to equivalent $CO_2$ concentrations of 437 ppmv, 827 ppmv and 1255 ppmv, respectively. These three time slices are commonly referred to as 1 x $CO_2$,
2 x $CO_2$, and 3 x $CO_2$, respectively.

The presentation at this climate change workshop included some of the topics in the project report; a presentation made by Mike Flannigan, December 2004, to Natural Resources Canada in Ottawa; and one additional topic included by the presenter, Brad Hawkes. The presentation covered the following topics:

- Current and future fire weather and danger scenarios for western Canada and British Columbia using RCM projections.
- Effectiveness of the RCM to simulate realistic fire danger projections for British Columbia.
- Changes in fire weather and danger that British Columbia can expect under a changing climate using comparisons to reference historic climate conditions.
- Historic fire occurrence and weather analysis: defining fire weather and danger relationships with biogeoclimatic zones; and Steve Taylor's (CFS, Pacific Forestry Centre) current research on determining fire probabilities in British Columbia from a historic fire database.
- Fire interactions with other disturbances, and forest composition and structure changes.
- What can be done to mitigate future changes in fire weather and danger?

## *Methods*

### *Improving RCM Projections for British Columbia*

Future weather projections for western Canada, as modelled by the RCM, were modified for the province of British Columbia. To reflect the elevation variations in British Columbia, elevation-correction routines were applied to the 45-km grid cell RCM temperature and relative humidity, while precipitation and wind speed were unchanged. As well, spatial relationships were developed to transpose the RCM data from a non-spatial to a spatial structure at the 5 km resolution. For each of the three scenario periods, 1 x $CO_2$ (1975–1985), 2 x $CO_2$ (2040–2049) and 3 x $CO_2$ (2080–2089), daily weather and Fire Weather Index (FWI) maps were created.

### *Comparing RCM Projections with Historic Actual Data for the 1975–1985 Period*

For the evaluation and validation of the RCM projections, it is important to understand how the RCM projections were created and to evaluate the proper elements. RCM projections are intended to predict broad weather patterns and trends. These projections do simulate day-to-day weather patterns but are not intended to be compared with actual observations on a daily basis. The best comparison of RCM projections is based on 10-year averages of either yearly or monthly periods. Thus, for the years 1975 through 1985, 10-year mean and mean 90$^{th}$ percentile maps were created from both the historic records and from the RCM projections. These maps were created for each of the weather and FWI variables for the Mayto August seasonal period and for each month of that seasonal period. Both data sets were adjusted by elevation-correction techniques.

### *Analysis of RCM Projections for the Future*

For each of the three RCM scenarios (1 x $CO_2$, 2 x $CO_2$, and 3 x $CO_2$), 10-year mean and mean 90$^{th}$ percentile maps were created for each of the weather and FWI variables for the May to August seasonal period. Delta maps, which compared the differences between the different scenarios (2 x $CO_2$–1 x $CO_2$ and 3 x $CO_2$–1 x $CO_2$) were generated to compare the effect of the future weather simulations.

### *Historical Analysis*

In order to understand the fire danger variability on a daily, monthly, and seasonal basis under future climate change scenarios, one must understand the present relationships between fire occurrence and fire weather. The relationship between fire weather, fire danger, fire occurrence and area burned must be developed and defined. These relationships were developed for the period 1953–2000.

From the historical weather records for 1953–2000, daily weather and FWI maps were created. These daily maps, which were created by means of the Spatial Fire Management System (sFMS), used the elevation-correction techniques to spatially enhance the data by incorporating the influence of terrain. These grids, which were stored in Arcview's Gridascci format at the 5-km resolution, represent an extensive collection of historical weather data.

In addition, using the historical fire and weather data sets in conjunction with the British Columbia biogeoclimatic (BEC) zones, bi-monthly grids and tables were also produced. An analysis was performed on these tables to generate relationships between fire occurrence, area burned, and fire weather on a BEC zone basis.

***Results***

*Current and future fire weather and danger scenarios for western Canada and British Columbia using RCM projections*

Although the RCM simulations of the three scenarios for British Columbia indicate a gradual increase over the next 100 years, the increase is not as severe as the RCM predictions for the rest of western Canada. In general for British Columbia, the future RCM scenarios are predicting an increase in temperature of 1 to 2ºC by the year 2045 and 2 to 4ºC by the year 2085, an increase in fire season length of 1 to 2 weeks by the year 2045 and 2 to 3 weeks by the year 2085, and an increase in Seasonal Severity Rating (SSR) over the three RCM scenarios. Projections of area burned, for the Canadian boreal forest and western Canada, based on weather/fire danger relationships suggest a 75 to 120% increase in area burned by the end of this century according to the Canadian and Hadley models, respectively (Flannigan *et al*. 2005).

*Continued next page…*

*Effectiveness of the RCM to simulate realistic fire danger projections for British Columbia*

In general terms, with due consideration to weather modelling techniques and spatial comparisons methods, the correlation between the RCM projections and the historic summaries for the 1975 to 1985 period are fairly close, both spatially and in magnitude. Temperature, Fine Fuel Moisture Code (FFMC), and Duff Moisture Code provided the best seasonal and monthly comparisons. The monthly comparisons improved as the season progressed. In most cases, the RCM was biased towards lower projections when compared to the observations.

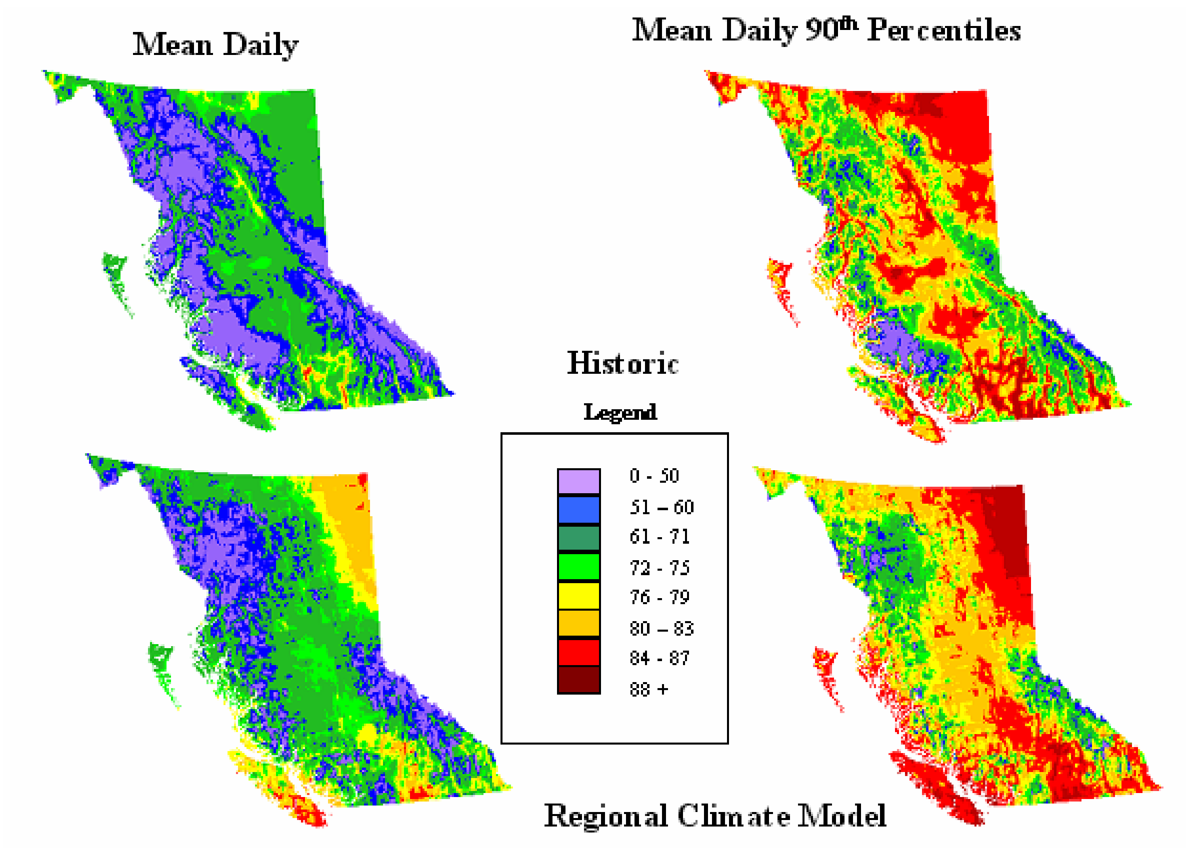


**Figure 1.** British Columbia historic and regional climate model (RCM) mean daily and mean daily $90^{th}$ percentile Fine Fuel Moisture Code (FFMC) based on 11-year August mean.

*Changes in fire weather and danger that British Columbia can expect under a changing climate using comparisons to reference historic climate conditions*

Delta maps for Build Up Index (BUI) indicated an increase of 2 to 6 and 2 to 6 by 2045 and 2085, respectively based on the 10-year seasonal means (May to August).
The 10-year mean 90$^{th}$ percentiles delta maps for BUI indicated an increase of 2 to 4 and 2 to 7 by 2045 and 2085, respectively. Delta maps for each of the weather and FWI values showed a gradual increase for all three scenarios. This increase was especially evident in the interpolation of temperature, Fine Fuel Moisture Code, and Duff Moisture Code.

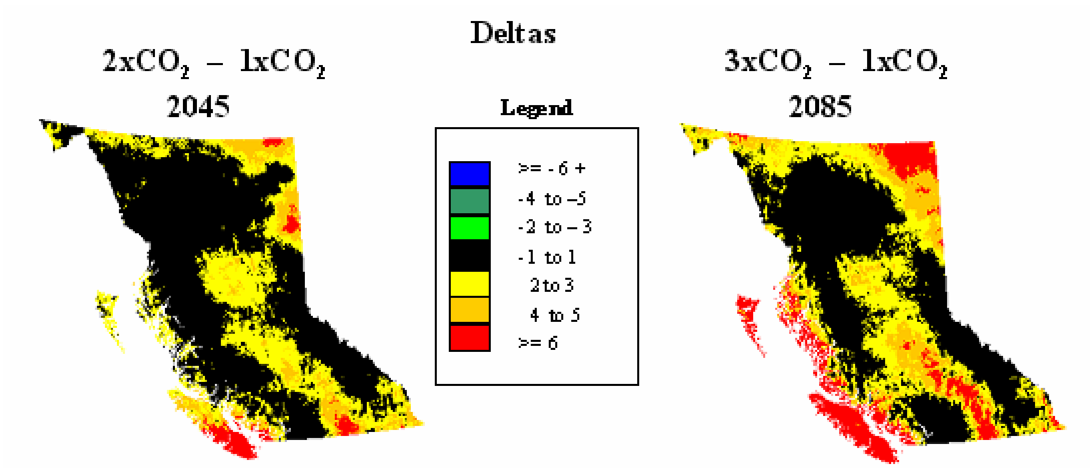


**Figure 2.** Delta maps for Build Up Index (BUI) for 2 x $CO_2$–1 x $CO_2$ (2045) and 3 x $CO_2$–1 x $CO_2$ (2085) based on the 10-year seasonal means (May–August).

*Historic fire occurrence and weather analysis*
*Defining fire weather and danger relationships with biogeoclimatic zones*

Most fires occurred in the Interior Douglas-fir, Interior Cedar-Hemlock, Engelmann Spruce–Subalpine Fir, Sub-Boreal Spruce, and Coastal Western Hemlock BEC Zones. The BEC analysis using bi-monthly and seasonal periods indicated a more significant relationship between BEC zones and human-caused fires than for lightning fires.

*Continued next page…*

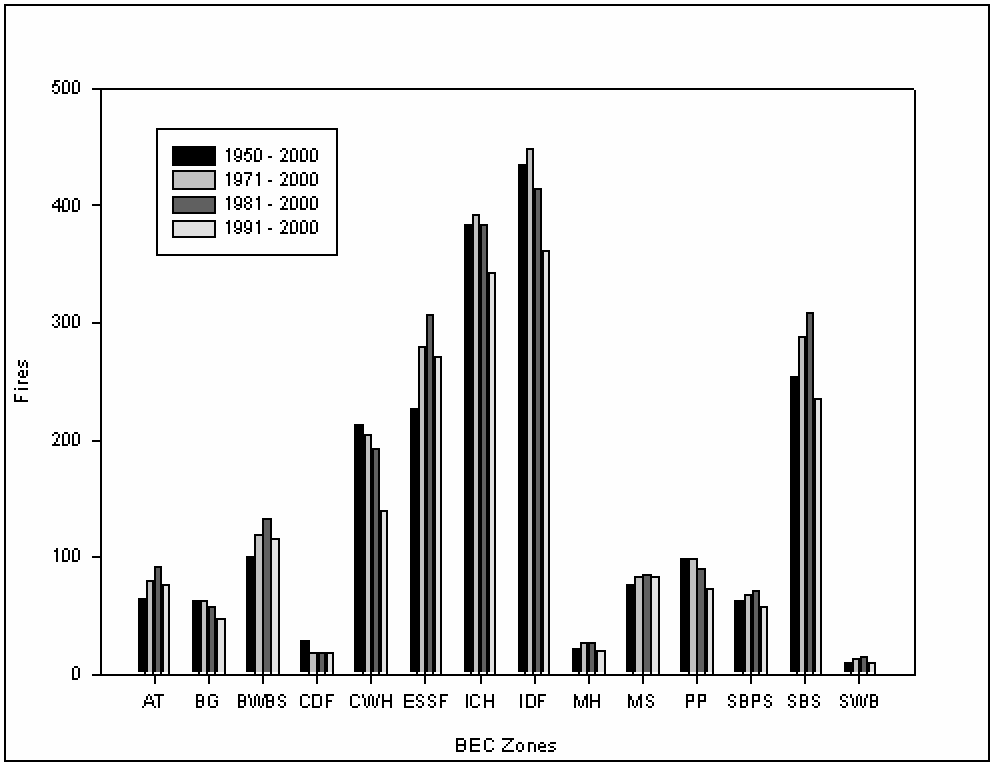


**Figure 3.** Mean person and lightning-caused fire occurrence by biogeoclimatic zone and four time frames.

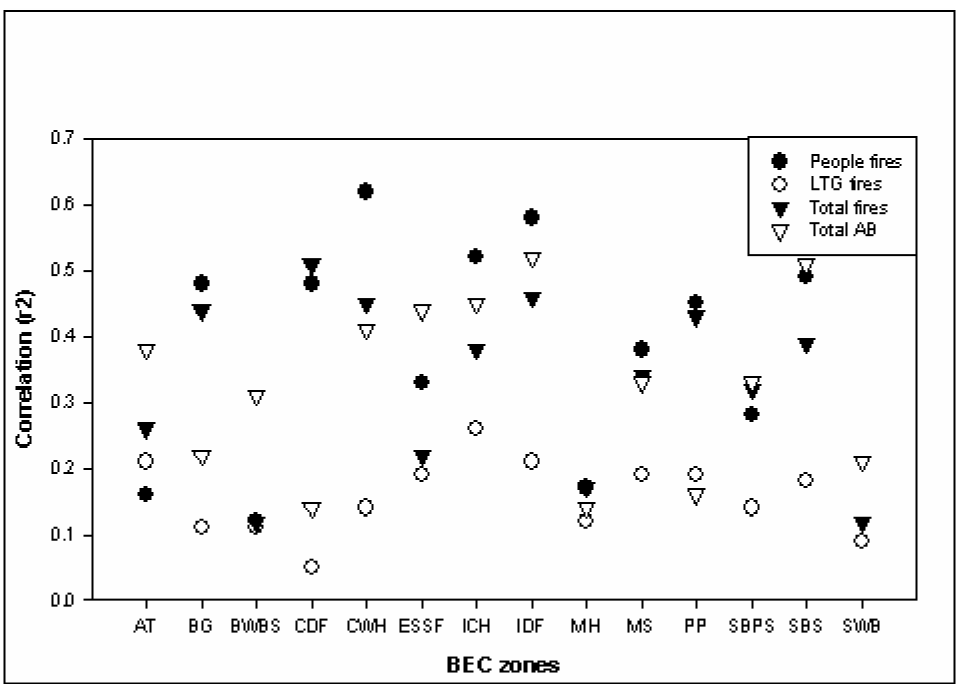


**Figure 4.** Statistical correlation of British Columbia fire occurrence categories for April to September season by biogeoclimatic zone.

There was a lot of variation between BEC zones and bi-monthly periods. The best predictors, based on the seasonal period analysis, for human-caused fires, were Fire Weather Index (FWI), BUI, and days since rain, while lightning fires were best predicted by mean temperature. The best predictor of total area burned, based on the seasonal period analysis, for human and lightning-caused fires, was FWI, mean BUI, and days since rain.

The significant relationships found among fire occurrence and area burned and BEC zones could be used in conjunction with other research projects, such as that described in this workshop by Andreas Hamann (Department of Forest Science, University of British Columbia), that presented climate change scenarios for movement of BEC zones and tree species associated with them. The combination of these could project future fire regimes in terms of BEC zone movement in British Columbia.

*Current research on determining fire probabilities in British Columbia from historic fire database (Steve Taylor, CFS, Pacific Forestry Centre)*

Taylor *et al*. (2005a) has modelled forest fire probability for British Columbia using a logistic regression approach utilizing mapped forest fires since 1920. Logistic regression models were fitted to lightning-caused, person-caused, and all fire data against 17 explanatory variables. Most of the variables made a significant contribution to predicting person-caused and lightning-caused fires. Some variables like road density, made a large contribution to explaining fire probability for both fire causes but for different reasons, that is, higher probability of person-caused fires near roads while lightning fire probability lowered with higher road densities, perhaps due to better access for fire suppression resources. Significant explanatory variables, such as FWI codes and indices, could be useful when combined with climate change fire danger scenarios since future changes in fire probability could be predicted using these fire danger scenarios.

*Fire interactions with other disturbances and forest composition and structure changes*

Taylor *et al*. (1998) modelled changes in forest composition and density in five study areas in interior British Columbia dry forests using 1950s and 1990s air photograph interpretation and the PrognosisBC growth and yield model. Forest density and cover increased during the approximate 40-year period and, using Prognosis BC, were predicted to become even denser. This change in forest structure and density increased the number of days in a reference historic fire season that crown fires would develop. There is an opportunity to link climate change scenarios of fire weather and danger to potential changes in forest conditions, whereby in theory there could even be a larger increase in the number of days in a fire season that crown fires would develop than without climate change.

Taylor *et al*. (2005b) examined whether there is an interaction between insect outbreaks and forest fire risk, or amount of areas burned. Eleven common forest insects were examined including four species of bark beetle and seven defoliating species. The hypothesis tested was that if forest insect outbreaks affected fire activity there would be significant variation in the waiting time distribution between outbreak and fire occurrence; that is, if insects had no effect then a uniform or random distribution would be expected. Tests on the median values of the normalized burn rate waiting time distributions suggested that mountain pine beetle, spruce beetle, western spruce budworm, and black headed budworm temporal patterns were significant. With potential changes, due to climate change, in insect outbreak frequency, intensity, and range (e.g., Carroll *et al*. 2004) combined with potential changes in fire weather and danger, occurrence and area burned, there could be stronger linkage between insect and fire disturbances.

*What can we do to mitigate future changes in fire weather and danger?*

There will be an increased need for society to be able to cope with increasing fire activity, especially with more Canadians living and working in the wildland urban interface. There will probably be more community evacuations, as well as smoke issues related to health and transportation. There are a number of potential mitigation strategies to reduce the potential impact of future changes in fire weather, danger, and fire activity. Landscape fuels management requires long time scales, especially for large areas. Fuels management can involve conversion, reduction, or isolation. Because of the potentially high cost of fuel mitigation strategies, fuel treatments need to be strategically located and be applied to enough of the landscape to impact large fire spread. The creation of FireSmart landscapes also involves individual landowners, as education, prevention, and emergency planning are needed along with landscape fire risk reduction strategies. The re-introduction of fire into protected areas and parks, where applicable, and the use of prescribed burning for ecosystem restoration and maintenance also play a large role in mitigating future changes in fire activity associated with climate change. Not all forested areas might receive the same level of fire protection, depending on fire risk and values that could be damaged by fire. There is a need for more studies of optimized level of protection related to land-management objectives.

New systems and models will be needed to balance multiple objectives for a landscape with disturbances that have been altered by climate change, such as fire, insects, wind, etc. A balancing act will be needed to manage for biodiversity (including habitat), harvesting, tourism and recreation, and carbon-budget objectives.

With fire activity likely to increase significantly with climate change (although with large temporal and spatial variability) integrated approaches will be required to adapt to increased fire activity in terms of social, economic, and ecological policies and practices. The forest industry, government agencies, and all Canadians must adapt for these potential changes in fire.

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## 6. Climate Change and Mountain Pine Beetle

*At the last minute Allan Carroll was not able to attend the workshop. Brad Hawkes kindly presented Allan's talk for him.*

Allan Carroll
Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre
Victoria, British Columbia
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Conclusions of the presentation were that:

- significant changes to climatic conditions relevant to forest pests have already occurred;
- relevant changes may be difficult to distinguish from impacts of forest management.

For more information on climate change and mountain pine beetle, please refer to a recent paper by Allan Carroll:

> Effects of climate change on range expansion by the mountain pine beetle in British Columbia. 2004. Carroll, A.L.; Taylor, S.W.; Régnière, J.; Safranyik, L. Pages 223-232 in T.L. Shore, J.E. Brooks, and J.E. Stone, editors. Mountain Pine Beetle Symposium: Challenges and Solutions, October 30–31, 2003, Kelowna, British Columbia, Canada. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, Information Report BC-X-399. 298 pp.

To find this paper online:

- Go to: http://bookstore.cfs.nrcan.gc.ca/default.htm .
- Once into the Canadian Forest Service bookstore search page, type in this title: Effects of climate change on range
- This will take you directly to Allan's paper.
- Then click on the title to download or view the PDF.

***Abstract***
The current latitudinal and elevational range of mountain pine beetle is not limited by available hosts. Instead, its potential to expand north and east has been restricted by climatic conditions unfavourable for brood development. We combined a model of the impact of climatic conditions on the establishment and persistence of mountain pine beetle populations with a spatially explicit, climate-driven simulation tool. Historic weather records were used to produce maps of the distribution of past climatically suitable habitats for mountain pine beetles in British Columbia. Overlays of annual mountain pine beetle occurrence on these maps were used to determine if the beetle has expanded its range in recent years due to changing climate. An examination of the distribution of climatically suitable habitats in 10-year increments derived from climate normals (1921–1950 to 1971–2000) clearly shows an increase in the range of benign habitats. Furthermore, an increase (at an increasing rate) in the number of infestations since 1970 in formerly climatically unsuitable habitats indicates that mountain pine beetle populations have expanded into these new areas. Given the rapid colonization by mountain pine beetles of former climatically unsuitable areas during the last several decades, continued warming in western North America associated with climate change will allow the beetle to further expand its range northward, eastward, and toward higher elevations.

### *Questions after Brad's Presentation on Mountain Pine Beetle*

Question:

What are some examples of insects that are exotic in this area, specifically Rocky Mountain Trench?

Response: (by Rene Alfaro, Canadian Forestry Service):

- Ambrosia beetles, some sawflies.
- The exotics usually come into ports, for example, Vancouver is a big factor. They arrive largely because of commerce.
- Exotics also arrive through campers traveling from one place to another, inadvertently carrying egg cases.

Response: (by Brad Hawkes)

- Please contact Eric Allan and Lee Humble at the Pacific Forestry Centre: www.pfc.forestry.ca

Question:

From what I hear, beetles are moving into plantations as young as 20 years old. Does anyone have any experiences with this, or can you give some reasons why this is happening? I just heard yesterday that they are also finding mountain pine beetle (MPB) in spruce trees.

Response: (by Brad Hawkes)

- Leo Rankin was speaking on this exact subject. Leo has all kinds of documentation. (Leo.rankin@gov.bc.ca ) Leo is a Forest Entomologist with the B.C. Ministry of Forests, Southern Interior Region.

Response: (by Rene Alfaro)

- Rene has not himself witnessed this, although there are lots of reports of this.
- Traditional wisdom that MPB only attacks trees of certain diameter, susceptibility is based on phloem thickness (previous knowledge). This understanding is based on wild forests, unmanaged. We are in an era of spaced, fertilized plantations; phloem thickness may be different for these beetles. He would not be surprised if through management, we are increasing the susceptibility of trees to beetle. Not sure whether this is permanent or just based on the surplus of beetles. He is looking at MPB tree susceptibility this summer.
- A tree is like a beetle factory. Big tree = lots of beetles. Small trees = fewer beetles.

Comment from audience:

In 1976 I worked out of Cranbrook. There was a huge MPB outbreak at that time. Small diameter trees were being killed. Apparently it was the very large population of beetles that were going after the trees that was causing these small trees to be killed. The same thing happened 10 years ago with the western hemlock looper attack. It was so intense that they were killing other types of trees. They were entering spruce trees. The loopers were so hungry that they were trying to defoliate spruce.

## 7. Climate Change Adaptation for Park Managers

David Welch
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***Abstract***

Protected areas management cannot contribute significantly to stopping climate change, but it can help the natural world adapt, and help educate society about its causes and consequences. I propose a range of actions for park managers to consider. Awareness of staff, Leading by example, Active ecosystem management, Research and Monitoring (ALARM).

***Why Adapt?***

Protected areas will be affected by climate change as much as other lands and waters in their natural regions. However, fewer mitigation and adaptation options exist for natural areas than for those that can be routinely manipulated. Park custodians must therefore adapt management practices to help maintain biodiversity and natural processes, to assist nature through her inevitable transitions, and to participate in communications and house-in-order programs. Adaptation is encouraged for several reasons.

- Climate change impacts cannot be prevented.
- Benefits will accrue from removing or halting maladaptive policies, practices, and stresses that increase vulnerability.
- Visitor activities and related infrastructure and marketing investments are tied to the timing and duration of climatic cycles and phases.
- Effective government is abetted by leadership by example. This means, for example, early achievement of greenhouse gas emission reductions from high profile institutions like parks.

***How to Adapt, Maybe***

The protected area/climate change literature provides strong reasons to have parks and reserves, why there should be more of them, why they should be accorded enhanced protection, and how they might be selected. For example, the recommendations of Hannah *et al.* (2002) and (Hansen *et al.* 2003) include the following:

- Locate parks with climate change in mind.
- Avoid fragmentation; provide connectivity and maintain buffer zones.
- Represent vegetation types and diverse gene pools across environmental gradients.
- Determine the necessity to transplant species.
- Control rapidly increasing species.
- Involve local communities for management of biodiversity.
- Strengthen research capacity, e.g., to model biodiversity under changing climates.
- Conduct long-term monitoring to seek causality between climate and biodiversity responses.

However, these and other reports provide little guidance to managers of existing protected areas. This paper attempts to provide guidance.

***What to Do***

I propose the following core principles for a climate change strategy for protected areas.

*House-in-order programs and public communications*
A park agency can foster mitigation by putting its own emissions house in order, and can use its outreach and presentation activities to demonstrate leadership. Visitors are generally ready to soak up information and listen to sound arguments by credible proponents. Indirect contributions through interpretation, education, and outreach can far exceed in-house emission reductions, but credibility depends on such reductions.

*Risk management*
Environments have a degree of resilience and, in some cases, can accommodate climate change by species migration or *in situ* adaptation. However, there are many other stresses impinging on ecological integrity, so I recommend a risk management approach whereby tractable stresses are reduced or eliminated. This can only happen through collaboration with stakeholders.

*Focus on mandate, complement with partnerships*
Protected areas increasingly emphasize ecological and commemorative integrity in their mandates, outweighing tourism development, infrastructure, and regional economic development. Leave unto others the leadership of activities that are their responsibility. However, to the extent that internal capacity allows and that one's prime mandate is favoured, cooperate in such activities. Education, emission reduction, and national science programs are good examples.

*Permeable landscapes*
Park agencies should promote the importance of regional ecosystems characterized by connectivity and permeability for wildlife movement. Permeability means not just defining wildlife corridors (connectivity), but removing impediments to movement across all lands. Examples include maintaining hedgerows and woodlots in agricultural areas, eliminating the cosmetic use of pesticides in urban areas, fostering dark sky preserves, and installing wildlife crossing alert lights on major highways (which is being done in a a Newfoundland pilot project).

*Targets*
Action plans need time-bound and measurable targets against which to assess progress and to redefine schedules and activities as appropriate. I propose three time frames and related goals.

- Short-term: Appropriate climate change information is available to ecosystem and asset managers.
- Mid-term: Climate change is factored into all aspects of ecosystem and asset management, and reflected in park management plans.
- Long-term: Parks are nested within landscapes that are porous for the movement of native species and free of other significant threats to ecological integrity.

## ***Alarming Actions***

Many actions can be conceived to fulfill these principles and goals, examples of which follow. They can be grouped under categories that form the acronym ALARM:

- Awareness
- Leading by example
- Active management
- Research
- Monitoring

### ***Awareness***

*Staff awareness*
Full engagement in any action depends on staff having an appropriate level of understanding of climate change impacts and adaptation. Actions include disseminating summary documents, newsletters and technical reports, giving seminar and workshop presentations, and including climate change overviews in basic training components.

*Stakeholder awareness*
Successful adaptation depends, in part, on the management of surrounding natural areas. Urge your ecosystem partners to adapt in concert. Ideas include extending awareness activities, promoting ecological porosity between and around protected areas, and mitigating local and regional threats to ecological integrity.

*General public awareness*
The public should be made aware of the impacts of climate change upon species, ecosystems and features, and what adaptations may be required. Interpretation programs should help visitors become aware of what they can do at home and at work, by direct actions and by spreading the word to their friends and family. Post a climate change summary on your web site. Work with education authorities and non-government groups to deliver climate change information to both children and adults.

### ***Leading by Example***

*Reduce greenhouse gas emissions*
Park agencies can use their favourable public profile to promote minimizing building energy consumption through design and operational practices such as reducing fleet size, switching to more energy efficient vehicles, fuel switching, and taking advantage of emerging technologies.

*Promote personal action plans for staff*
Employees and volunteers can play a role through their personal actions at home and in their neighbourhoods. Employers can provide transit passes rather than subsidizing parking. They can provide incentives for car pooling, cycle commuting, telecommuting, and promote energy-use reductions in homes and lifestyle choices.

*Address climate change adaptation in park management plans*
Given the enduring nature of parks and the long-term implications of climate change, adaptation should be addressed in management plans. For example, modify park purposes to protect processes and biodiversity rather than specific biomes and species. Review boundaries to seek opportunities for

changes that optimize the protection and maintenance of ecological integrity. Endorse research and monitoring of indicators of climate change impacts. Take future climate and vegetation successions into account in ecosystem restoration projects such as fire restoration and land reclamation.

*Report on natural and management adaptations to climate change*
Whether reactive or adaptive, an integral part of management is the monitoring of progress towards a goal, assessing results, and modifying future actions accordingly. Documenting these processes is essential to full debate and support. A regular report series is the best guarantee of systematic publishing, dissemination, and readership. Annual corporate reports and periodic state-of-park reports are often appropriate. Select indicators of climate change impacts for your park and its natural region, develop protocols and implement monitoring, and collaborate with regional partners to report impacts to the public and policy makers.

### ***Active Ecosystem Management***

*Adapt natural region representation strategy*
As a basis for park establishment, natural region representation assures a distribution of parks across landscapes and ecotones, itself one of the best ways to protect biodiversity. It also deflects demands for land protection when there is already a park representing a specific region. Natural regions are typically based on physiography and vegetation. While physiography remains largely constant in anything less then geological time, vegetation has changed significantly in living memory. Climate change will accelerate this process to the extent that natural successions will evolve within decades. Therefore, retain map entities of natural regions but revise their descriptions to reflect the dynamics of present and future climate.

*Eliminate or mitigate non-climate in situ threats*
The growing body of research on interactions between climate and non-climate stresses suggests that responses are synergistic. To maintain or rebuild ecosystem resilience one must reduce the number and/or magnitude of insults faced by an ecosystem. Fortunately, many stressors are more locally and regionally controllable than climate change. In a freshwater system this may require limiting the concentration of toxic substances in effluent. In a forest ecosystem it may mean preventing fragmentation by access roads. These tasks are approachable on a local level through conservation partnerships.

*Use adaptive management*
The uncertainty about the exact nature of climate change impacts and responses requires a responsive, flexible approach to ecosystem management. Adaptive management allows one to proceed with only limited or uncertain knowledge. An intervention is conducted as if it were a scientific experiment, with measurable, time-bound targets set in advance, careful measurement of results as thing happen, and approaches adjusted as new information becomes available. Use adaptive management in impact abatements such as species protection or retardation of invasive pioneers.

*Use climate change research results*
It is not enough to have good primary science. There must be secondary products that digest and customize this knowledge for interdisciplinary professionals. Commission reports that translate the science to regional- and park-specific data sets. Parks Canada has done this through the work of Scott (2003) which resulted in spreadsheets of annual, seasonal, and monthly temperature and precipitation

data for several scenarios at three periods of the 21st century, accompanied by narrative projections of potential physical and biotic changes.

Park managers also need tools to use climate change information in their decision-making processes. Climate change guidelines for environmental assessment are now available in Canada, covering projects that either have the potential to emit greenhouse gases, or projects that will be impacted by climate change.

*Adjust park boundaries as needed for climate change adaptation*
Changes in climate will lead to changes in habitats and species survival. Some plant species would have to migrate hundreds of kilometres to follow climate. Others might find a new home a short distance away. For the latter it may be possible to adjust park boundaries to capture the anticipated movement of habitats and species. Park boundaries could be realigned to accommodate transition zones where large changes of climate, habitat, and species distribution are expected.

### ***R*esearch**

Understand the impact of past and future climate change. Decision makers and park visitors alike benefit from a knowledge of Holocene landscape changes. This helps to understand the changeable nature of climate and nature's ability to adapt autonomously, even in historical times. Research the impacts of climate change on natural processes and visitor activities before committing to ecosystem restorations or visitor infrastructure development. Rate each park for its sensitivity to a 3 x ($CO_2$) atmosphere.

*Identify values at risk of being significantly impacted by climate change.*
Identification of valued ecosystem components (VECs) provides a means to set management goals without bogging down in the minutiae of all species, all minerals, and so forth. Identify a limited suite of VECs that are sensitive to climate change, such as species at the margins of their climatic range, species with limited or excessive abilities to migrate, and temperature-sensitive features such as permafrost and ombrotrophic wetlands. Identify barriers to migration such as fragmented habitats and restricted vertical migration paths.

### ***M*onitoring**

*Gather data and report actions*
Each park should have long-term climate and climate change indicator data. These data should be reported at the park level and regional or national levels.

*Promote parks as long-term integrated monitoring sites*
Integrated monitoring can reveal unexpected linkages between ecosystem components and the drivers of environmental change. Each stress does not need its own unique set of indicators. Often, several stresses can be tracked from a limited but well-selected ensemble of indicators. Integrated monitoring also fosters partnerships in which many agencies share costs while reaping benefits greater than the sum of their inputs.

### ***What Not to Do***

*Do not move parks to anticipated biomes*

The presence of a well-distributed system of protected areas is one of society's best adaptations to climate change. Species will have their best chance of finding new homes in a well-managed, well-distributed, well-connected, and properly sized network. While some parks might benefit from local boundary adjustments to protect ecosystems and habitats at risk from climate change, the notion of dynamic parks must be rejected for a number of reasons. First, this would open the door to other reasons to move a park, for example, to extract minerals or fibre. Second, few natural areas remain for new park establishment within regions that already have park representation. The present parks are often all that remain as natural havens. Third, park establishment is a lengthy process with no guarantee of success.

*Do not use parks to buffer or mitigate other impacts*
Parks are not an insurance policy to cover poor management of natural hazards and natural resource supply. The restoration, protection, and maintenance of natural systems preclude their manipulation to counter an anthropogenic threat. Ecosystem services may come about with the maintenance and restoration of ecological integrity, but parks should not be manipulated deliberately for flood protection, water supply, or carbon sequestration, for example. This could open the door to the commercialization of natural resources in parks.

*Do not change natural regions to fit future biomes*
The natural region representation approach to national park establishment has served Canada well since its adoption by the federal cabinet in 1976. Since then, the constancy of the number of regions and their boundaries has been a cornerstone of the national park system plan. It helps to deflect lobbying to add a park just to satisfy vested local interests. If the precedent were to be set that the natural regions policy could be changed, then there could be no end to further pragmatic modifications of regions and parks.

All climate scenarios are based on assumptions about future emissions, the physics and chemistry of the atmosphere, and geographical simplifications to allow global models to operate on today's supercomputers. Vegetation response is likewise modelled on plant succession assumptions. While these represent today's best science, the placement of boundaries remains notional and subject to change as models improve and as the world develops real emission inventories rather than scenarios. To change natural region boundaries on this basis would open up a never-ending process, and create an unrealistic setting for park feasibility studies and establishment negotiations.

### *Conclusions*

A good network of protected areas free of other stresses is already one of society's and nature's best available adaptations to climate change. Park agencies can also influence visitors and the general public, but this in turn requires well researched and monitored climate change impact indicators as the basis for adaptive ecosystem management, accountability, and reporting systems. House-in-order programs complement the messages that governments should send to their people. Research on the synergy between climate change and other processes can provide the knowledge to guide the mitigation of local and regional stresses, thereby restoring natural resilience of ecosystems and wild species.

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### ***Questions after David's Presentation***

Question: (from Brad Hawkes, Canadian Forest Service)

> We are not going to be involved in mitigation: some mitigation is occurring, for example by protecting facilities, interacting with burns (controlling how they move or don't move). It is affecting the forest structure.

Response:

> A park agency cannot mitigate climate change other than by participating in government house-in-order programs. Furthermore, it should not be Parks Canada policy to contribute to carbon sequestration as this would be in direct conflict with the legislated goal of protecting or restoring ecological integrity

Question:

> Sixty percent of parks recognize climate change in their management plans. What are some examples?

Response:

> In 2001, I conducted a survey of air issues in the national parks, forty-one in total. Twenty-three (56%) addressed climate change in a management plan or other formal document such as a scoping document, monitoring plan or specific resource conservation plan. These parks are: Aulavik, Auyuittuq, Banff, Bruce Peninsula, Forillon, Fundy, Grasslands, Gwaii Haanas, Ivvavik, Kejimkujik, Kluane, Kouchibouguac, La Mauricie, Nahanni, Prince Albert, Prince Edward Island, Pukaskwa, Quttinirpaaq, Riding Mountain, Terra Nova, Tuktut Nogait, Vuntut and Waterton Lakes. Since then, at least two other parks can now be counted in, Sirmilik and Wapusk, as they are joining our other Arctic national parks in a combined monitoring strategy that will track, among other things, the impacts of climate change on ecosystem values. Other parks may also be addressing climate change as they enter their regular management plan revision process. So we can say that at least 61% of parks, and probably closer to three-quarters, recognize climate change in their management planning process.

## 8. Climate Change and Biodiversity: A Global Perspective

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### *Introduction*

Although this conference focuses on regional impacts of, and adaptation to, climate change, these occur in a global ecological and political context. Canada is currently in the throes of implementing its commitments to the 1997 Kyoto Accord, but the federal government's plan and associated policies and legislation are not without controversy. How climate change may affect ecosystems that we can see from here will be determined by events far beyond our borders. To understand the changes that we may see here, we need a global perspective. This paper first outlines the features of the climate system that cause temperature and precipitation variations at eon, millennium, and decadal scales. Next, I review trends in key forest disturbance indicators since the first assessment of ecosystem effects of climate change in British Columbia in 1994 (Harding 1994a; Harding 1994b; Harding and Taylor 1994). Finally, I present three case histories that demonstrate Canada's ecological and political linkage to climate-related events in other countries: Brazil, Jordan, and China. I will conclude with remarks on regional and national implications.

Although "climate change" information relates mainly to changing temperature and precipitation resulting from greenhouse gas emissions, the term also encompasses other atmospheric features that may affect species at risk, or their habitats, including increases in the concentration of carbon dioxide ($CO_2$, a plant nutrient) and increases in ultraviolet radiation (UV-B). The latter, which is harmful to plants and animals, is a consequence, not of the major greenhouse gases such as $CO_2$ and methane, but of ozone depletion caused by chlorofluorocarbon (CFC) releases. Stratospheric ozone, which protects against UV-B exposure, has been progressively depleted since about 1979 in northern temperate and polar regions, including Canada, with consequent increases in UV-B exposure (Fioletov *et al*. 2002). Releases of CFC have been largely controlled in most industrial countries (for example, by mandating the use of non-CFC gases in refrigerators and automotive air conditioners), but the nature of CFC interactions with other atmospheric gases and with sunlight ensures that the primary effect of ozone depletion will persist for many decades after emissions have stopped. This report focuses on the consequences of changes in temperature and precipitation, not because $CO_2$ and ultraviolet radiation are irrelevant, but because there is little information about them that would support projections of effects at regional levels in British Columbia.

### *Methods*

This review is based on published and grey literature, with some statistics from the World Wide Web. Some of the material on recent climate trends in British Columbia and ecosystem response has been abstracted from Harding and Diamond (2005).

### *Past and Future Trends*

For at least the last 2.5 million years—from the beginning of the Pleistocene epoch—glacial and warmer interglacial periods have alternated on approximately a 100,000-year cycle, called the Milankovitch Cycle. It is actually the result of the varying congruence of three cycles:

- A 105,000-year cycle in the shape of Earth's orbit, from a more elongated to a less elongated ellipse.
- A 41,000-year cycle in the tilt of the earth's axis relative to an axis perpendicular to the orbital plane.
- A 21,000-year cycle, the precession of the equinoxes, during which the moment in the year at which the earth is closest to the sun, as it traverses around its elliptical orbit, shifts forward from January through February, then March, and so on around to January again.

The 41,000 year cycle resulting from the tilt of the earth's axis has more effect at high latitudes, such as in British Columbia. Pielou (1991) illustrated the effect of these cycles on temperature as shown in Figure 1.

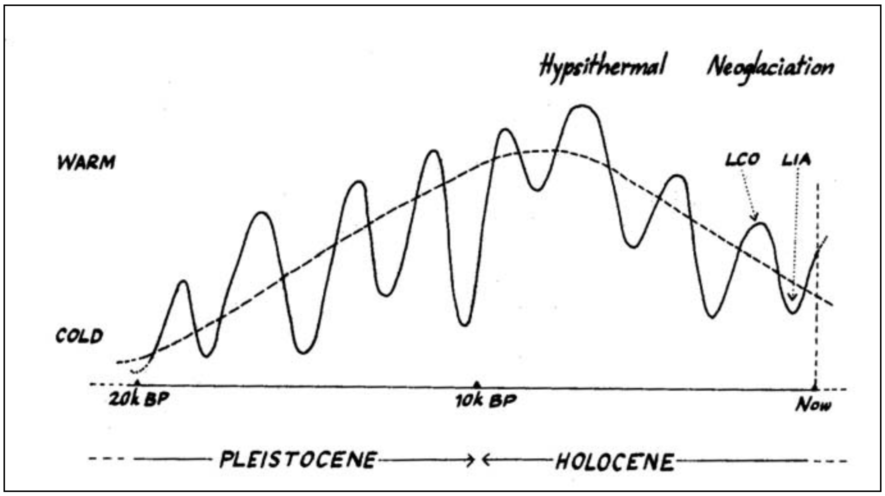


**Figure 1.** Effect of the Milankovitch Cycle on global temperatures (from Pielou 1991). LCO is the Little Climatic Optimum and LIA is the Little Ice Age.

Prior to the rapid rise in industrial-age greenhouse gas emissions, the global climate was cooling, possibly towards another ice age. Indeed, many climate scientists felt that the Holocene was merely another interglacial period and that we could anticipate future glacial episodes typical of the Pleistocene. The cooling trend began to be arrested about 8,000 years ago, coincident with a rise in $CO_2$ that may have been associated with the rapid increase in deforestation and agriculture in Europe, about 5,000 years ago. This warming coincided with an increase in methane released by flooded-land rice cultivation in southeast Asia (Ruddiman 2003). Figure 2 (from Ruddiman 2005) illustrates the possible (and still controversial) linkage between early agriculture and climate change.

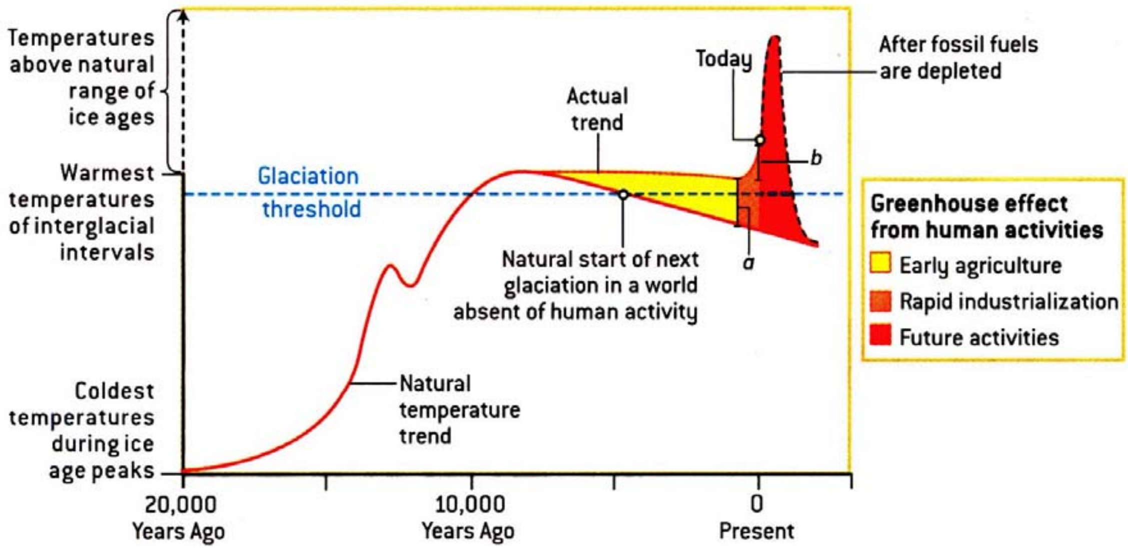


**Figure 2.** Millennium-scale temperature variation with and without anthropogenic emissions (From Ruddiman 2005).

The current climate crisis must be viewed in the context of these cycles and long-term trends.

In the last century, global mean temperatures rose about 0.6 ºC, at least partly due to a well-documented, sharp increase in anthropogenic greenhouse gas emissions (Houghton *et al*. 2001). Figure 2 shows the trend for the northern hemisphere.

Globally, the year 2003 was the second warmest on record, jointly with 2002 when values are rounded to two decimal places (Jones and Moberg 2003). The 1990s was the warmest decade in the series. The warmest year of the entire series was 1998, with a temperature of 0.58°C above the 1961–1990 mean. The 10 warmest years globally have now occurred in the 1990s and 2000s. They are, in descending order, 1998, 2002 and 2003 (joint), 2001, 1997, 1995, 1990 and 1989 (joint), and 1991 and 2000 (joint). Analyses of over 400 proxy climate series (such as tree rings, corals, ice cores, and historical records) show that the 1990s was the warmest decade of the millennium and the 20th century the warmest. The warmest year of the millennium was 1998, and the coldest was probably 1601.

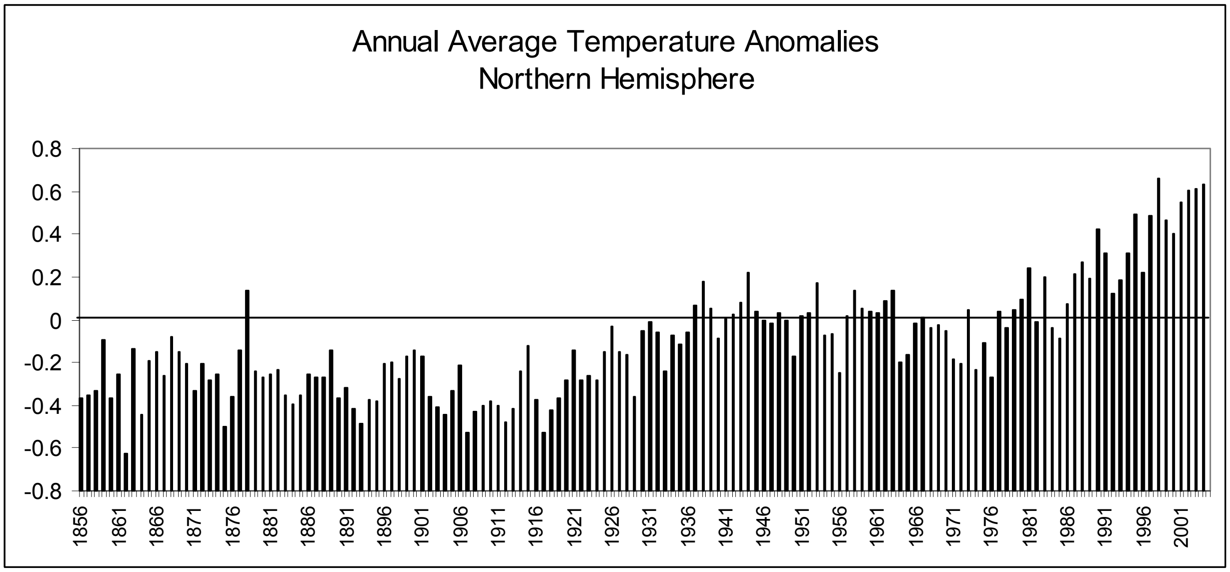


**Figure 3.** Temperature anomalies (deviations from average) for the Northern Hemisphere, 1856–2003 (data from Climatic Research Unit, University of East Anglia, Norwich).

In British Columbia, the detection of trends is complicated by two irregular phenomena of the north Pacific that affect regional weather patterns. The first is El Niño/Southern Oscillation (ENSO), a periodic (2–7 years) invasion of the north Pacific by warmer equatorial waters that brings warmer temperatures and winter storms accompanied by high precipitation and wind (Zebiak and Cane 1987). The second is the Pacific Decadal Oscillation (PDO), a poorly understood source of ocean ecosystem and climate variability in Pacific Northwest that was in a negative (cool) phase from 1900 to 1925, then a positive (warm) phase until 1945, another cool phase until 1997, a warm phase until 1998, and finally back to a cool phase (Figure 4) (PICES North Pacific Ecosystem Status Report Working Group 2004). Both the ENSO and PDO warm phases tend to coincide with winter and spring weather that is warmer and drier than average in the Pacific Northwest (a study area that includes the Fraser Lowlands), and cool phases tend to coincide with cooler, wetter weather (Mote 2003).

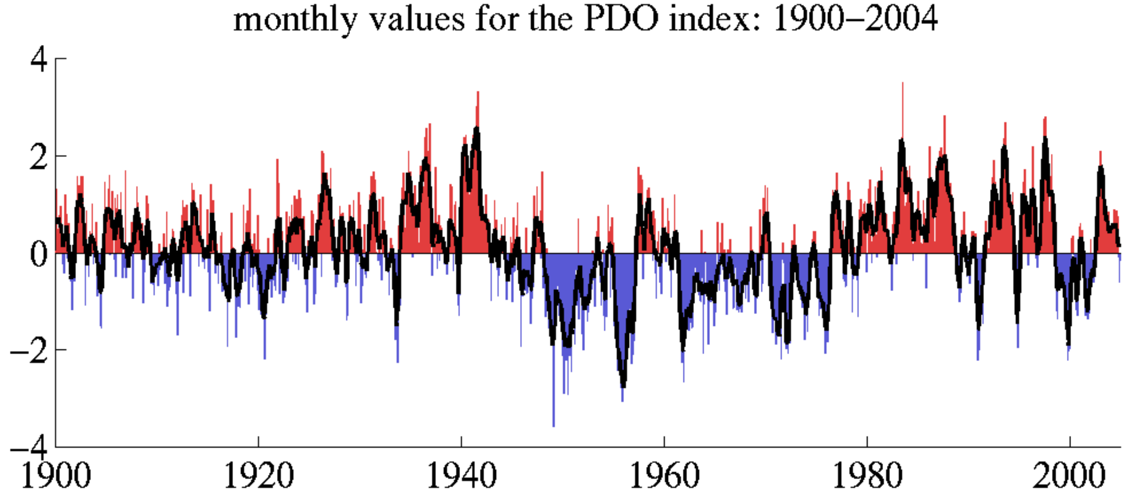


**Figure 4.** Trends in the Pacific Decadal Oscillation (PDO) index 1900–2004 (fromwww.tao.atmos.washington.edu).

***Ecosystem Effects in British Columbia***

Both El Niño and the PDO have profound effects on marine and terrestrial ecosystems throughout the Pacific Northwest. For example, forest fires (annual area burned) in western Canada are influenced by the PDO (Skinner *et al*. 1999). The climatic effects produced by these oceanographic phenomena greatly complicate the search for weather trends and consequent ecosystem effects that may be associated with global warming. Nevertheless, some trends in forest disturbance regimes that were possibly linked to climate change were noticed as early as 1994, and the associations between them have become stronger since then.

In 1994, in an assessment of threats to forest biodiversity in British Columbia, I reported a trend in insect infestations that was consistent with predictions of ecosystem effects of global warming (Figure 5) (Harding 1994b).

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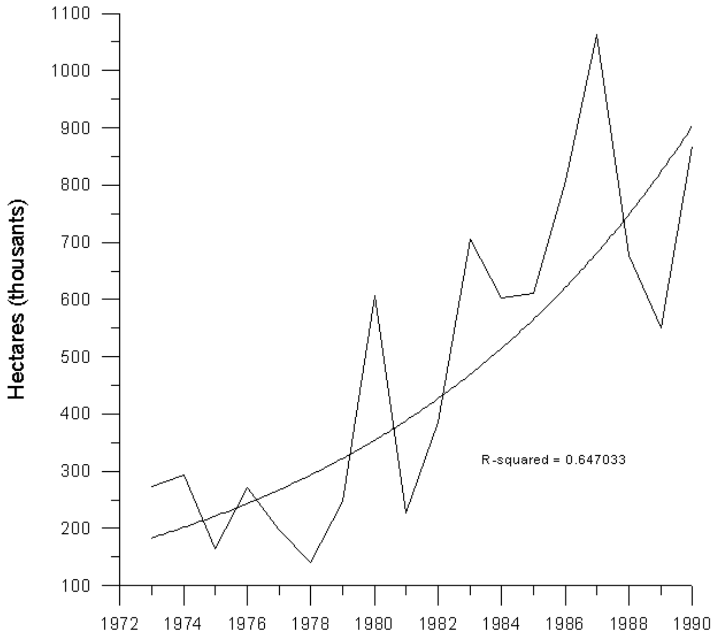


**Figure 5.** Area affected in British Columbia forests by the six most damaging insect pests, 1972–1990 (adapted from Harding 1994).

These insect species contributing to the trend in the above graph were the mountain pine beetle (*Dendroctonus ponderosae*), western spruce budworm (*Choristoneura occidentalis*), two-year cycle budworm (*C. biennis*), western black-head budworm (*Acleris gloverana*), and tent caterpillar (*Malacosoma disstria*). The increases were both in the area of the infestations and in the range of some of the insect species, including the western spruce budworm, the spruce bud moth (*C. fumiferana*), and the mountain pine beetle (Harding 1994b). The hypothesized linkages to global warming were that:

- warmer winter temperatures were allowing some insect species to survive over winter in regions where frost had previously killed them;
- in the Prince George region, earlier onset of spring weather allowed some species to complete two full reproductive cycles;and
- in at least one case, summer drought so stressed Douglas-fir trees that they became more susceptible to Douglas-fir tussock (*Orgyia psuedotsugata*) moth damage.

In the same report, I noted that, "...with global warming, forest pests may increase." (p. 271), and "Hot, dry summers [will] encourage outbreaks of Douglas fir tussock moth…" (p. 252).

Both the observed trend and the prediction were controversial at the time, because, as critics pointed out, (a) global warming was not well established, and (b) although the trend of damage by all insects was clearly increasing, no single species of insect showed consistent trends.

Nevertheless, the insect damage trend continued. The mountain pine beetle infestation continued to intensify and to expand northward during the 1990s, clearly linked to both global warming (Carroll *et al*. 2004; Williams and Liebhold 2002) and the fire-suppression era maturation of pine forests (Taylor and Carroll 2004). By 2003, a total of about 11 million cubic metres of commercial timber had been added to the allowable annual cuts of four northern forest regions to combat the spread of the mountain pine beetle outbreak (from www.for.gov.bc.ca, January 9, 2005).

By 2004 (B.C. Ministry of Forests 2005):

- the mountain pine beetle infestation reached 7 million ha (Figure 6);
- the western balsam bark beetle (*Dryocoetes confusus*) infestation reached 2 million ha;
- the western spruce budworm had damaged 623,825 ha; and
- The large aspen tortrix (*Choristoneura conflictana*) had damaged 429,526 ha.

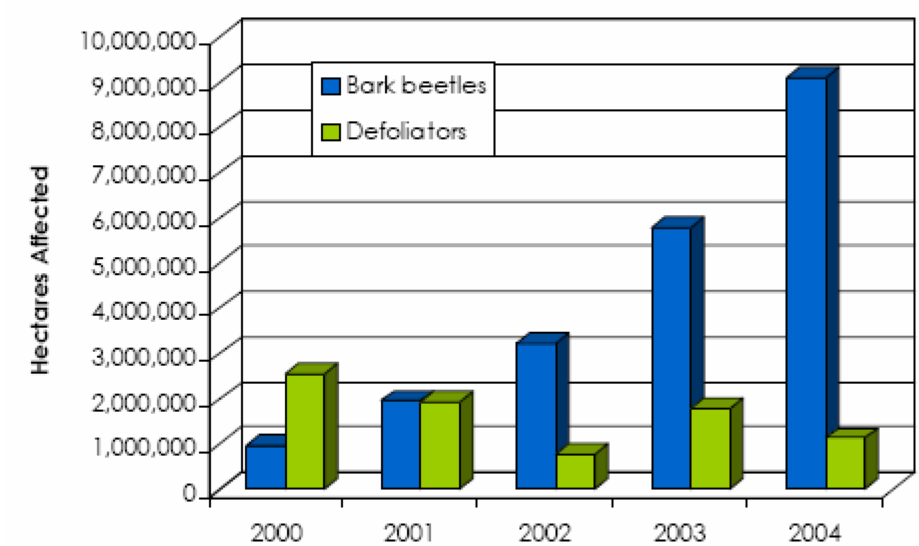


**Figure 6.** Mountain pine beetle infestation trend, 2000–2004 (from the B.C. Ministry of Forests 2005).

Combining climate change scenarios with future climatically suitable habitats suggests that the mountain pine beetle will continue to expand its range northward, eastward, and toward higher elevations (Carroll *et al*. 2004).

The linkage of insect pest infestations to global warming is well illustrated by the Douglas-fir tussock moth. Figure 7 shows the recent trends, as measured by the number captured in B.C. Ministry of Forests sampling (B.C. Ministry of Forests 2005). The two peak years in the last decade—1998 and 2003—were also the two warmest years on record.

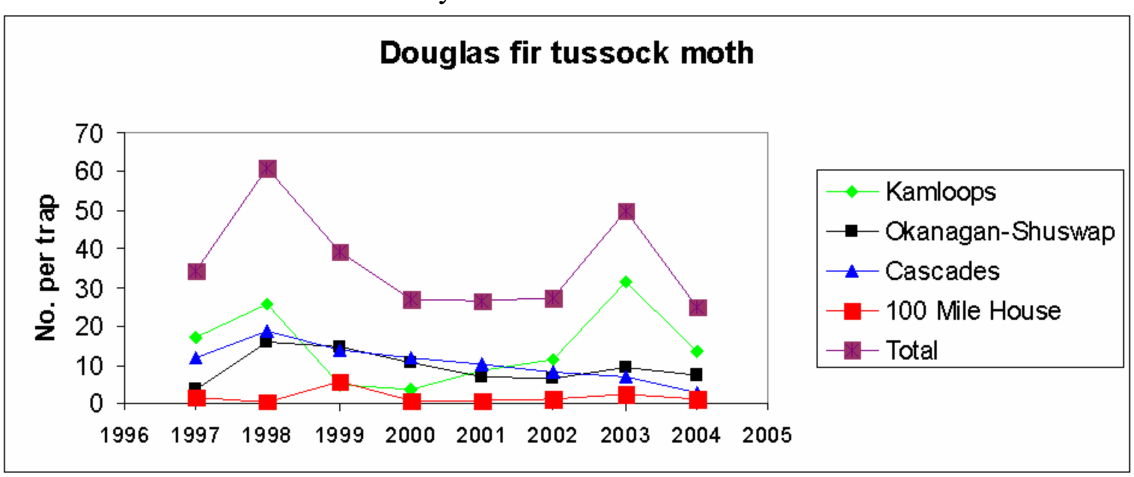


**Figure 7.** Recent trends in the Douglas-fir tussock moth (from the B.C. Ministry of Forests 2005).

Fire disturbance trends are more difficult to quantify because of the aggressive intervention. In 1994, I reported that forest fire frequency in British Columbia had been increasing but that the area burned had not, ostensibly because of the fire prevention program. I also suggested that global warming would bring "…further increases in forest fire frequency" (p. 274).

Since then, however fire frequency has declined, reducing the strength of upward trend (Figure 8). The peak year of 1994 was not a particularly warm year, but the two warmest years on record—1998 and 2003—were high in both fire frequency and area burned (Figure 9).

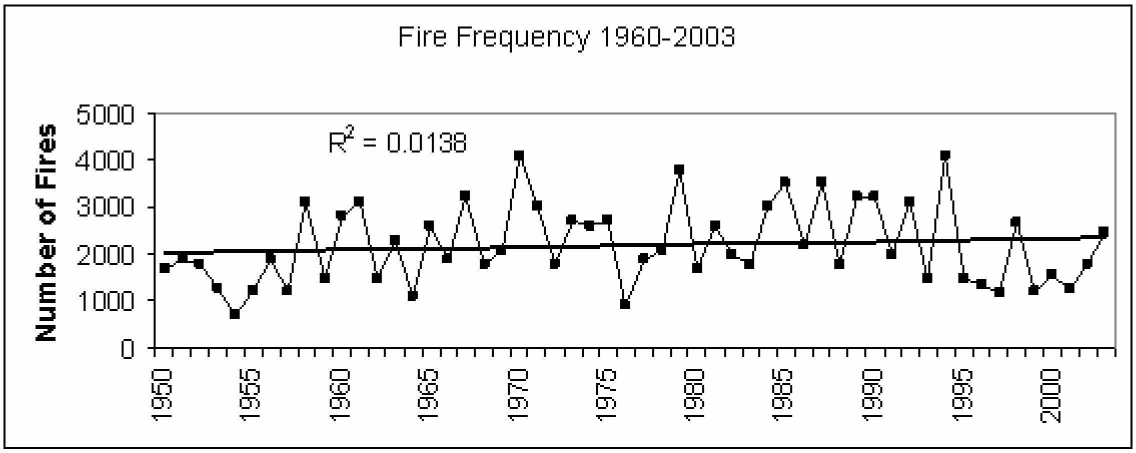


**Figure 8.** Fire frequency in British Columbia, 1950–2004 (adapted from Harding 1994 with 1990–2004 data from www.for.gov.bc.ca ).

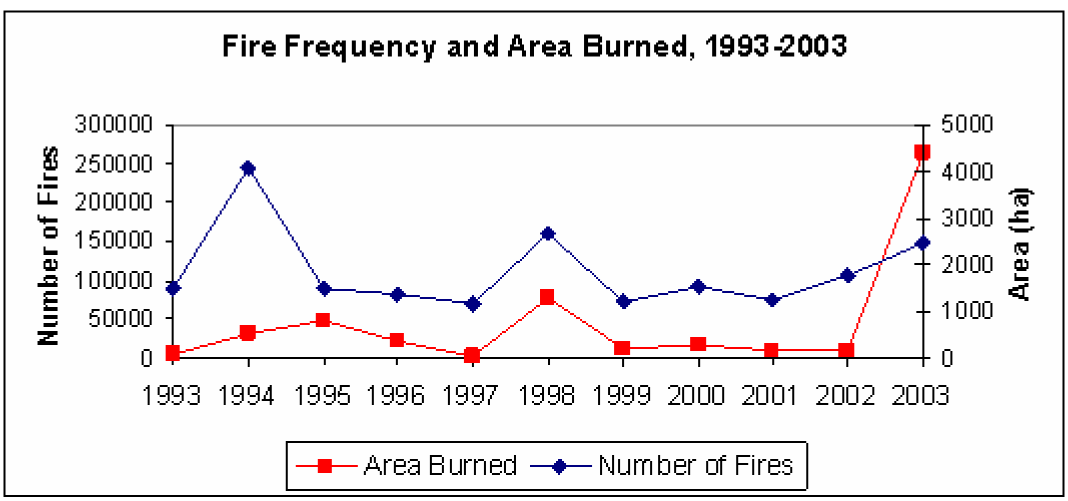


**Figure 9.** Recent (1993–2003) fire frequency and area burned in British Columbia (from the B.C. Ministry of Forests 2005).

The impact of weather on fire frequency and area burned is so well established that such weather variables as rainfall, humidity, and soil moisture have been used to project the severity of approaching fire seasons for fire suppression planning (Flannigan *et al*. 2001). The paleological record shows that, during past phases of the Holocene (that is, after the Earth warmed following the last Pleistocene ice age), warmer periods were also drier and were accompanied by higher rates of forest fires (Hallett and Walker 2000; Hebda 1998).

Throughout Canada, human-induced climate change has had a detectable influence on the area burned by forest fire in recent decades. Continued increases in annual area burned are likely to have important implications both for terrestrial emissions of carbon dioxide (as a climate change feedback mechanism) and for forest ecosystems (Gillett *et al*. 2004).

Because climate change is a global problem, it will take a global perspective to fully appreciate its effects on Canada. The following three case studies highlight three regions where decisions about climate change will have repercussions in Canada.

***Ecosystem Effects in Other Countries: Three Case Studies***

Canada is connected via climate change to other countries, not only through negotiations to control the release of greenhouse gasses through such international instruments as the 1997 Kyoto Protocol, but also through the climate system itself and the biological systems that depend on it.

Net Primary Production (NPP, amount of solar energy converted to plant matter through photosynthesis) varies globally, responds to climate variations, and is a fundamental factor in the development of ecosystems. The average annual NPP (1982–1998) is about 120 billion tons (Imhoff *et al.* 2004). Humans "appropriate" about 20%, unevenly distributed; large urban centres consume 300 times the amount produced locally, while sparsely populated but highly productive regions like Amazonia, humans appropriate approximately 0% (Figure 10). Because the human appropriation of NPP can be used as a surrogate for the impact of humans on ecosystems generally, it also represents an index of greenhouse gases emissions. Three regions are selected for this analysis to represent a range of scenarios of how other countries' climate change decisions may affect Canada: Amazonia, the Middle East, and east Asia.

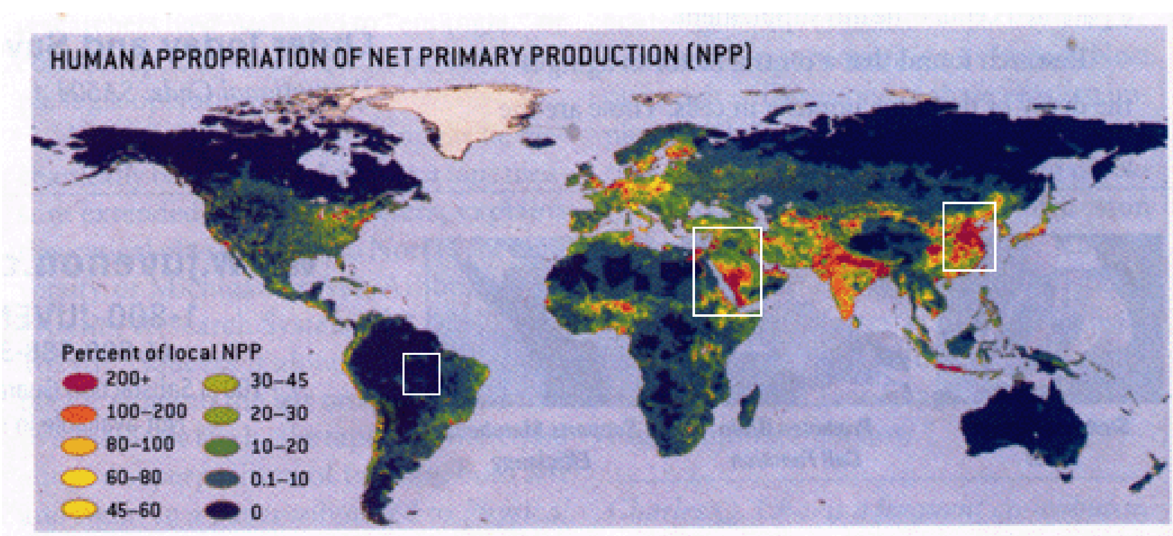


**Figure 10.** Human appropriation of NPP (from Imhoff *et al*, 2004 and NASA image from the Goddard Space Flight Center). The white boxes show the regions discussed herein.

### *Amazonia*

Forests are critical components of climate change because they sequester carbon dioxide. Plants, which make up much of the biomass of forests, consume $CO_2$ during growth and release it when the land is cleared through combustion or other oxidation processes. Globally, forest cover declined 33% since the last ice age to 6 million km$^2$.

About 47% of all forests are tropical, 9% subtropical, 11% temperate, and 33% are boreal. Seven countries hold 60% of the planet's forests: Brazil, Canada, China, Indonesia, Russian Federation, United States, and Democratic Republic of Congo. There is also a social dimension: 56% of the world's forests, including most tropical forests, are in developing countries. Over 145,000 km$^2$ of natural forest are lost each year.

Tropical forests, of which those in the Amazon Basin are the most extensive, contain much of the world's biodiversity. More than 50% of the world's terrestrial species are found in tropical forests. Canada has an investment in Amazonian forests through its promotion of the Biodiversity Convention and through shared biota. Forests in Amazonia are connected to those in Canada in these ways:

- Some neotropical migrant birds that nest in Canada breed in Amazonia.
- Carbon dioxide emitted by the clearing of Amazonian forests, or that fails to be sequestered by the growth of Amazonian forests, will contribute to global warming that affects Canada.
- Countries with Amazonian forests, including Brazil, Bolivia, Peru, Ecuador, Columbia, and Venezuela, are involved, as Canada is, in controlling greenhouse gas emissions through such international conventions as the 1997 Kyoto Accord.

In Brazil, which holds most of the Amazon Basin, there has been a 40% increase in deforestation since 1992, ironically, the year that the Biodiversity Convention was signed (Figure 10). Brazil's deforestation rate for 2003 was 23,750 km$^2$; a rate of 0.60% per year (World Wildlife Fund and Center for International Forestry Research, www.cifor.cgiar.org/docs/_ref/publications/newsonline/36/beef_exports.htm). Most (38%) is for cow pasture, and the bulk of this is clearing for single-family use.

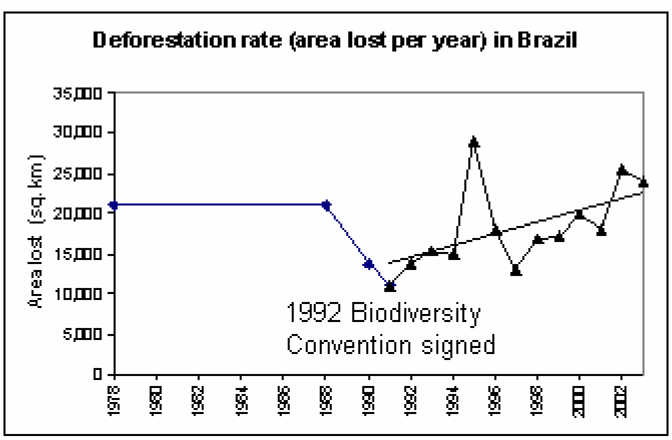


**Figure 11.** Deforestation rate in Brazil (data from the National Institute of Space Research.)

The total area of forest lost in the Amazon rose from 41.5 million ha in 1990 to 58.7 million ha in 2000.

About 200 species of birds breed in Canada and winter in the tropics. Most are insectivores that consume the insect pests that are currently ravaging our forests, and some populations are declining because of tropical deforestation. Harding (1994a) reviewed evidence for a connection between tropical deforestation and the decline in neotropical migrant birds and hypothesized that a decrease in these insectivores could reduce a natural mechanism of control of forest insect pests in British Columbia. Other factors, such as climate warming trends and forest management practices, clearly dominated the increase in infestation rates noted previously, but declines in neotropical migrant birds could be a factor.

This relatively minor and hypothetical, but direct, ecological connection to Canada, is overshadowed by more profound connections of the physical features of climate change that have political, social, and economic implications. Canada is connected to Brazil economically (through trade and through loans via the World Bank), socially (through a variety of international and intergovernmental mechanisms designed to promote social advancement and trade), and politically (through international treaties such as the Kyoto Protocol). Canada intends to use forest management practices, particularly the planting and rapid growth of young forests, as carbon emission “credits” to avoid having to actually reduce $CO_2$ emissions. To gain international acceptance of this approach, Canada has spent a great deal of scientific energy researching forest carbon fluxes and a great deal of political energy negotiating and lobbying internationally on how these “credits” will be calculated and applied to Canada’s obligations under the Kyoto Protocol. Brazil, which is even more extensively forested than Canada, will benefit from the same agreements, and will similarly gain emission credits to offset industrial greenhouse gas emissions. In the end, greenhouse gas emissions will continue to rise in both countries and the impact of climate change on Canada’s ecosystems and industries will continue.

The solutions to the deforestation component of Brazil’s greenhouse gas emission inventory are social (and political, to the extent that the country’s policies affect the social well-being of its indigenous citizens). This is because most of the forest clearing is for single-family, subsistence-farming use f by people who have few other options. Therefore, the rate of deforestation in Brazil, and hence the rate of tropical deforestation-related greenhouse gas emissions that drive climate change in Canada, will depend in part on finding economic solutions to poverty among the indigenous population.

### *The Middle East*

Middle Eastern ecosystems are mainly arid or semi-arid and, as such, are extremely moisture-limited and very susceptible to climate variables that affect precipitation and soil moisture. Jordan is an interesting case study because it straddles the 50 mm precipitation/year isopleth that divides grassland from desert; it also straddles a variety of political and religious divides that make its policies, including those related to climate change, critical to peace in the Middle East.

Unless otherwise cited, information in this section is from two reports I prepared for the Hashemite Kingdom of Jordan (Consolidated Consulting 2002a; Consolidated Consulting 2002b) and follow-up studies in 2003.

About 80% of Jordan is arid rangeland, 10% is grassland, and 10% is Mediterranean woodland (Figure 12). The arid rangeland supports about 3 million sheep, goats, and camels herded by semi-nomadic

Bedouins, while the grassland supports field crops such as wheat and barley. The Mediterranean woodland supports orchard fruit (mainly olive, peaches, apricots, pomegranates) and nut tree production in the mountains, and vegetable production in the Jordan Valley. A few isolated desert oases support date, orchard, and vegetable crop production, and are important water sources for livestock.

Livestock production has increased since the 1970s as the Bedouins have acquired trucks to transport water to their flocks, rather than having to bring their flocks to water. Consequently, overgrazing has become a feature of the desert ecology in Jordan, and a feature elsewhere in the Arabian Peninsula. Prior to the 1990 Gulf War, the livestock population was 1.4 million sheep and 0.4 million goats, donkeys, and camels; however, in that year, approximately 1.8 million of these animals were brought into Jordan by Bedouins fleeing Kuwait and Iraq, sharply worsening the already-severe overgrazing.

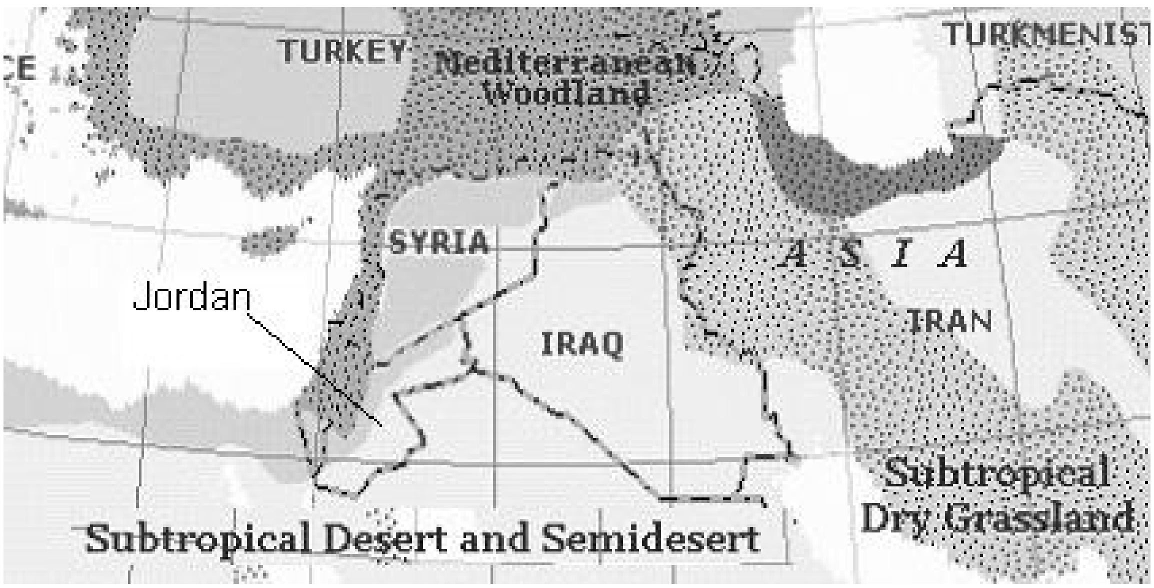


**Figure 12.** Middle Eastern ecosystems (from the World Wildlife Fund). The unstippled grey zones are grassland.

Projected climate change in Jordan will have these features (Houghton *et al*. 2001):

- Temperature will increase 1 to 2°C by 2030–2050.
- Evaporation will increase; soil moisture will decrease.
- Recharge of aquifers and oases will diminish.
- Grassland (10% of Jordan) will shrink.
- Semi-arid rangeland (80% of Jordan) will become arid desert.
- The rangeland supports about three million sheep, goats, and camels.

This means that the 50 mm ppt/yr isopleth, south of which no grain crops can be grown, will contract to a narrow band along the Jordan Valley. Subtropical dry grassland will contract northward and subtropical desert will expand northward. The 7.2 million ha of semi-arid rangeland that now supports 3 million sheep and goats will be become arid desert.

Jordan is one of the most water-limited countries in the world. Its water resources include four aquifers, three oases, Yarmouk River, Jordan River, Wadi Araba, Dead Sea, Wadi Mujib (site of Mujib Dam), and Zarqa River. There are 21 dams (most are small). New projects are the Mujib Dam (completed), a new dam on the Yarmouk jointly with Syria, and the proposed Red Sea–Dead Sea pipeline, which has been discussed with Israel for years. All of the aquifers have been depleted except for Disi-Mudawara inn the Ma'an-Tabuk Valley that straddles the border with Saudi Arabia.

With hardly any all-year surface water, Jordan's only options are to harvest the runoff from rare, but vigorous, rainfalls during the winter, and to mine fossil water from aquifers. This, however, brings it into conflict with its neighbours. Israel and Syria share seasonal runoff with Jordan in the Jordan and Yarmouk Valleys, respectively, and Saudi Arabia shares a large, as yet undeveloped aquifer with Jordan. Jordan has almost gone to war with all of its neighbours over water (it has gone to war with Israel over other issues and conflict over water in the Jordan Valley and Wadi Araba are constant irritants in continuing tense relations).

All of Jordan's borders are heavily fortified and the threat of invasion is very real:

- With Saudi Arabia, the border is fenced, ditched, and garrisoned.
- With Israel, the border is fenced, mined, and guarded with heavily artillery emplacements at frequent intervals.
- With Iraq, the border has a ditch, barbed wire, and an army garrison. The region (the Badia) is used by Jordanian Bedouins and by Syrian, Saudi, and Iraqi Bedouins who sneak across the borders.
- With Syria, the border is mined on both sides and guarded by the army in accessible areas and by the camel-mounted Bedouin Border Guard in other areas.

In 2002, my team of Jordanian ecologists and I were free to go anywhere in the country (although we were briefly detained at a military command post when our habitat investigations took us too near the Israeli border); however, in 2003, after the United States invaded Iraq, we required a special top-level government permit and a military escort to visit our study sites east of Amman.

Within Jordan (as with other Arab countries), the Bedouin tribal traditions dominate land and resource politics. Outside of Amman, which has the bulk of the population, about 98% of the population are,at most, two generations removed from nomadism while about 65% of households are still semi-nomadic, travelling most of the year with their flocks in search of forage and water (Dutton 1998). Nomads have been considered a national security threat to the country's rulers since at least Roman times because of their tight knit, although dispersed, communities, traditional culture, mobility, and lack of respect for borders. To ensure loyalty and protect sovereignty, the King confers financial and other benefits to the tribal Shaykhs. Many tribes are wealthy; even wealthy families—especially wealthy families—keep large herds of sheep, goats, and camels for cultural and religious reasons. Tribal leaders decide who will go to university (thence into business or politics), who will join the Badia Patrol or army, and who will herd the sheep, goats, and camels. In Jordan, Bedouins control parliament, dominate the army, and have lucrative businesses.

In these circumstances, anything that disrupts the social and economic relationships among the Bedouin tribes and between them and the government, could affect the direction of the whole country. Climate change has the potential to do just that by reducing water resources and by converting arid rangeland to subtropical desert, with no substantial support for grazing livestock. Canada has substantial interests in Jordan, ranging from its participation in the Ramsar Convention (one of the oases likely to go dry if the water situation worsens is a Ramsar site that formerly hosted millions of migratory birds in winter) to a variety of development aid initiatives.

Jordan's stability could also affect Canada's relations with our largest trading partner, the United States. When Canada refused to support America's 2003 war in Iraq, it won the admiration of many Arabs and worsened our relationship with the United States, which has been reflected in several areas of trade. Jordan, as the closest country to a democracy among the Arab states, occupies a pivotal position in Middle East politics. Climate change, by disrupting water resources and causing a drying of the rangelands, could greatly exacerbate current tensions and upset the current, tenuous peace to the detriment of Canada.

### *China*

It would be hard to overestimate China's role in the global carbon budget. Because of its rapid industrialization, China is now one of the world's top $CO_2$ emitters. Its social and economic trends have included the following:

- Until the 1990s, virtually all private and a huge amount of light industrial and agricultural transportation were by hand-cart, bicycle, or public transportation.
- A rapid rise of the middle class accompanied rapid industrialization.
- People are eating better, living longer and buying more cars.
- Although China's fecundity rate is kept low by the one-family, one-child policy, the population continues to increase.

China's $CO_2$ emissions rose rapidly from 1978 to 1996. However, they then fell 17% by 2000, as a result of new hydroelectric power (principally the giant Three Gorges Dam) and closing of coal-fired plants. Emissions in the United States grew by 5% in the same period. Canada's also grew.

Coal power provides 70% of China's supply, compared to 24% hydroelectric power. In 2005, China stopped construction of 22 more coal-fired power plants. If construction resumes, its $CO_2$ emissions will overwhelm other countries' efforts to meet Kyoto.

Shanghai ,in its entrepreneurial drive to western-style financing and development under the Communist system, is a microcosm of the country In 1993, when I first visited Shanghai, there were virtually no private cars, only busses, trucks, taxis, and 7 million bicycles for the 14 million people. In 2003, the human population had increased by another 2 million (6 million, if outlying cities are included), the number of bicycles had increased at a lower rate than the people, and 200000 private cars were in use.

Automakers expected to sell four million vehicles in China in 2003, compared with 3.2 million in 2002, according to China Association of Automobile Manufacturers (http://english.people.com.cn/200304/23/eng20030423_115646.shtml). In 2004, Shanghai GM successfully launched the Cadillac brand.

Massive deforestation accompanied China's "Great Leap Forward" in 1966–1970, partly to fuel iron smelting and other metal recycling ordered by the central government for every segment of society (even elementary schools operated crude recycling plants, melting down metal chopsticks and bronze treasures confiscated from the "bourgeoisie"). However, equally massive reforestation and afforestation since 1980 has changed the $CO_2$ sequestration from negative to positive. Like Canada, China uses this to meet the Kyoto Accord requirements instead of cutting emissions.

Climate change both affects and is affected by China's land-use history. Mid-continental drying in the northwest, which may be a feature of climate change, exacerbates the erosion caused by past deforestation. This has resulted in massive soil loss throughout China's main wheat-growing regions and is doubtless at least partly responsible for the endemic dust storms experienced in Beijing. Runoff has become increasingly rapid, with less water retained in groundwater and other natural systems. Flooding has increased and irrigation has been disrupted. The Huang He (Yellow River), northern China's major river system, now dries up for several months per year; its sediment load annually extends the estuary by 20 $km^2$ per year into the Bohai Sea.

In 1997, China became a net importer of food, as previously predicted by Lester Brown of the WorldWatch Institute (Brown 1989). This was because China's growing population outpaced its food production, which was increasing at a slower rate, in part due to land degradation and water scarcity, but also because many (mainly coastal) Chinese people were richer and therefore eating more meat, fish, and poultry, and feeding more grain to their growing livestock and poultry populations. Agriculture can not expand much because of technical limitations and is further threatened by urban sprawl, soil contamination, irrigation water loss, and hydroelectric dams. Coastal fisheries are depleted, but fish production has continued to increase from offshore fisheries; these too, however, are rapidly being depleted,

The implications of all this for Canada the following:

- China must maintain a strong economy to buy food on the international market, which will be good for Canada's wheat sales, but portends ill for China (and the world) if global wheat production should ever decline—a high probability in global warming scenarios (Houghton *et al*. 2001).
- China's $CO_2$ emissions will affect climate much more than Canada and will determine the success of Kyoto Accord.
- The example of China's inverted population and food balance shows that Canada cannot count on international trade to supply essential commodities forever.

## *Conclusions*

Climate change is not a hypothetical issue that can be left for future generations. I was among the scientists who made correct predictions about its effects on British Columbia's ecosystems; these effects have now been amply documented as observed trends. Moreover, British Columbia's ecosystems do not exist in isolation from the rest of the world. The three case studies presented here are, admittedly, rather speculative, but so were my earlier works on ecosystem response to climate change (Harding 1994a; Harding 1994b; Harding and McCullum 1997; Harding and Taylor 1994), which have since been validated. The case studies suggest the following.

- Canada's forests and grasslands are ecologically connected to those in Amazonia by bird migration and atmospherically to those in Amazonia and China through the global atmospheric $CO_2$ balance, and politically through the Kyoto Accord.
- Global warming may destabilize the Middle East through effects on water and rangelands, with trade and security implications for Canada.

- Global warming may destabilize China through effects on food production, which willl ripple through countries that supply China's food, including Canada.

How our forests, rangelands, and hydrological regimes respond to climate change will depend in large part on how other countries control their emissions. Protecting our forests and other ecosystems from climate change will be determined more by the actions of other countries than by Canada's response to climate change. British Columbia can defend its ecosystems from the effects of climate change by urging the national government to vigorously implement the 1997 Kyoto Accord and to participate with countries in related initiatives. Our goal should not be to minimize the economic impacts of complying, but to minimize the potentially catastrophic ecological and economic consequences of not having an effective international response to climate change.

### *Acknowledgements*

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***Questions after Lee's Presentation:***

Question:

Give us perspective on how climate change will affect the Pacific Northwest and how that will affect us?

Response:

- Despite Environment Canada's insistence that they will never sell our water, Lee thinks we will have to deal with repeated proposals to divert water to the southwest United States, where global warming will exacerbate the existing water shortage.
- A lot of our species are on the endangered list and are at the northern end of their range. As they move here, they may cause pressure to de-list species if they increase in numbers. Conversely, other species may withdraw to the north and some, particularly those of high mountain and peri-glacier habitats, may simply lose habitat and decline in numbers. The changing lower elevation habitats will favour grassland-steppe species over our current mix of grassland and forest species. If we don't have the monitoring in place, we may not notice the changes in numbers and distribution.

Comment from Richard Hebda:

One very positive issue: Discussion is occurring and it hasn't happened before. Information from the south of us is being shared. Globally, traditional agricultural could help to put some of the carbon back in the soil. Pay people to live in traditional ways in developing world? Make soil not war.

Question:

We've heard about local and global issues. What efforts are being made for education of people in the Amazon?

Response:

Brazil, Jordan, and China all have educational programs. Jean Chrétien talked about this at a climate conference in South Africa in 2002 and made the front page in *Jordanian Times* when he announced that Canada would ratify the Kyoto Protocol. But the rural people of all of these countries know or care little about international conventions. Their governments must speak for them. But it is not the people who are producing the carbon dioxide and consuming the forests in these countries, it is the large corporations (state industries in China), as is in Canada. And as in Canada, the solution lies in government regulation of emissions.

# 9. Towards a General Model of Avian Response to Climate Change

Fred L. Bunnell presented this information.
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### *Introduction*

There is ample and widespread evidence that some bird species are responding to the current trend in global warming (Burton 1995; Fiedler 2001; Lehikoinen *et al*. 2004). Published responses through time or in response to global warming differ both among species and among regions (Lehikoinen *et al*. 2004, Sparks and Carey 1995). British Columbia hosts about 410 bird species that occur with some regularity, all of which could respond somewhat differently. There is need for some general model of expected response to allow agencies time to consider what mitigative actions are possible and where they are possible. Here we offer our initial thoughts on such a model and preliminary tests of predictions.

### *Bird data*

We selected only eight species to present a range of natural history features. The number of species was necessarily restricted because data had to be entered electronically prior to analysis, and for some species covers a period of 118 years. For evaluating temporal trends we restricted the database to include only single records for any location on any date. That is, one record was considered sufficient to confirm the presence of a species in a given area on a given date. This restriction avoided the bias resulting from extensive or long-term study in any particular area, especially those focused on a single species, which produced a large pulse of records dominating underlying trends. A second form of bias has resulted from sampling effort, reflecting that these are cumulative observations over more than a century. Such potential bias had its greatest impact on measures of abundance or potential range expansion. We corrected for this using rarefaction curves (see Preston 2005). The species used (and their sample sizes after reduction to eliminate multiple records for a single location) are summarized below. Sample sizes addressing questions of abundance or range expansion included the entire database, and typically were twice the size of those used to evaluate trends.

**Common Loon** (COLO) *Gavia immer*: 60,968 occurrence records and 2,028 breeding records over 113 years. Migrates into the interior of the province to nest on lakes, ponds, marshes, and rivers. Forages for fish, crayfish, leeches, and other aquatic animals in clear water. A partial migrant, arriving inland shortly after the ice melt, which should respond to climate change.

**Yellow Warbler** (YEWA) *Dendroica petechia*: 19,476 occurrence records and 996 breeding records over 118 years. Primarily insectivorous but occasionally supplements its diet with berries. Forages by gleaning and hawking insects and spiders on the limbs of trees and bushes, primarily deciduous. Small insect larvae and caterpillars are preferred. A riparian obligate, and thus is susceptible to changes in riparian vegetation. It is found in riparian woodlands throughout the province, and in the north is particularly abundant in the Boreal Plains Ecoprovince. Over the past two decades, this bird has shown significant declines in numbers in both coastal and interior regions.

**Swainson's Thrush** (SWTH) *Catharus ustulatus*: 18,900 occurrence records and 950 breeding records over 115 years. Diet is primarily insects such as beetles, ants, caterpillars, Hymentoptera; secondarily: flies, bugs, grasshoppers, spiders, millipedes, snails, sow bugs, earthworms, and a variety of berries. Young fed mostly insects and their larvae, supplemented by berries. This thrush breeds throughout the province and, like the Common Loon, provides the opportunity to evaluate whether it is responding uniformly to climate change throughout the province.

**Lewis's Woodpecker** (LEWO) *Melanerpes lewis*: 7,628 occurrence records and 618 breeding records over 114 years. This woodpecker is a weak-excavator nesting primarily in dead trees, which are frequently removed by forest practices. Summer diet is primarily flying insects; fruits, berries, and seeds are eaten during late summer and fall. Unlike most of the other species examined, it has no strong affinity to water. The apparent northward extension of its range into central British Columbia is poorly understood.

**Sandhill Crane** (SACR) *Grus canadensis*: 5,950 occurrence records over 112 years. The coastal subspecies *Grus canadensis tabida* is blue listed within the province. Significant portions of the world's population of *G.c rowani* (interior) and possibly *G.c. canadensis* (northeast) migrate through the province seeking traditional staging areas, such as agricultural fields and grasslands, often near water bodies. Nesting habitats include shallow wetlands such as marshes, swamps, bogs, ponds, meadows, and lake margins. All habitats are susceptible to effects of climate change. Opportunistic feeders taking snails, crayfishes, worms, mice, birds, frogs, snakes, and many kinds of insects, as well as roots, various seeds and fruits, and other aquatic vegetation.

**Surf Scoter** (SUSC) *Melanitta perspicillata*: 9,727 occurrence records over 115 years. The Surf Scoter feeds mainly on mollusks, crustaceans, aquatic insects, small fishes, and infrequently on green plant matter such as pondweeds, and seeds of sedges and bulrushes. Nesting habitat includes bogs, ponds, and shallow lakes surrounded by muskeg or mature spruce and mixedwood forest in the boreal forest. These habitats could be readily affected by climate change and drying.

**White-winged Scoter** (WWSC) *Melanitta fusca*: 8,093 occurrence records over 113 years. White-winged Scoters dive to feed on mollusks, crustaceans, aquatic insects, and small fishes; summer diet also includes submerged aquatic plants in inland areas. Nesting habitat includes relatively acidic bog lakes in the boreal forest. These habitats could be readily affected by climate change and drying. As well, this scoter is harvested by coastal First Nations as food.

**Wilson's Phalarope** (WIPH) *Phalaropus tricolor*: 3,088 occurrence records and 52 breeding records over 82 years. This bird feeds mainly on aquatic and terrestrial insects And appears to be undergoing a longer-term range expansion in the province since the 1940s. However, it frequents relatively shallow water—sloughs, ponds, marshes, lakes, and flooded meadows that could be depleted with climate change.

***General Model***

Life history traits can be used to make predictions of likely responses to climate change. The initial division of the general model uses migratory status of the species. Further subdivisions are based on features such as body size, capacity for multiple broods, food habits, and “income” versus “capital” breeders. Income breeders arrive lean and must replenish themselves before breeding, whereas capital breeders replenish their reserves effectively en route and can begin breeding shortly after arrival. Based on these features we are trying to develop predictions for a species’ response in terms of arrival date, departure date, (thus length of stay and potential changes in over-wintering), range expansion, abundance, clutch initiation, and clutch size.

*Resident species*

There can be no change in arrival or departure dates, but we expect range expansion northward within the province. If British Columbia represents the northern edge of their range, we also expect increases in abundance. The latter response would serve to increase provincial stewardship for the species. Altitudinal belts for the species should shift higher. Currently, we expect no range contractions due to climate, because there is little tendency yet for the province to become drier. We expect the breeding season (clutch initiation) to begin earlier. This group is least likely to show a mismatch with phenology of food resource because members can exploit all local environmental cues. Given that temperature minima are increasing faster than temperature maxima, frequent extension of the breeding season is expected among variable brooders. That again will result in increased abundance and increased provincial stewardship. We expect that such a response will be evident primarily among species already capable of variable brooding. Those frequently producing two broods should show larger clutch size in the second brood than has been true historically. All reproductive responses likely will be influenced by the phenological response of the primary food source during breeding. For example, we expect insectivores (especially those associated with deciduous trees) and piscivores (limited by ice on lakes) to show the strongest responses in early arrival and subsequent reproduction. Body size or periods of incubation and care for the young may create further restrictions. Larger body size and longer incubation and care periods may encourage earlier breeding, but limit the opportunities for extending the breeding season by multiple broods.

*Partial migrants*

We consider partial migrants to be species that over-winter primarily in British Columbia, but migrate to breeding ranges within the province. Out-of-province migrants may augment their numbers. Analyses of arrival and departure must be designed to keep over-wintering individuals from obscuring trends.

These species are constantly monitoring regional environments and should respond quickly to climate change. Generally, we expect earlier arrival, later departure, increasing abundance of resident individuals (greater stewardship responsibility), range expansion northward (increasing stewardship for species historically wintering primarily outside of British Columbia), and earlier clutch initiation in many species. These species are unlikely to show a mismatch between breeding and the phenology of food resources because they are exploiting regional cues. For those species with the capacity, we should see an extension of breeding season and the proportion of multiple broods. That should also appear as increased abundance and greater stewardship. Most single brooders (e.g., larger birds) will be sufficiently constrained by other features so that they cannot produce multiple breeds, resulting in a potential change in relative abundance among multiple and single brooders. As with other species, responses are expected to be constrained by the phenological response of the primary food source during breeding and body size. For those partial migrants over-wintering in coastal waters, El Niño Southern Oscillation (ENSO) or sea surface temperature (SST) may influence both timing and subsequent breeding success.

*Short-distance migrants*
We define short-distance migrants as having some portion of the wintering population within 1000 km of the 49th parallel, which is approximately 38°N or central California. Although the distance is short, there may be a potential distinction between "capital" breeders (arrive with fat deposits and breed quickly), and "income" breeders (must acquire breeding reserves upon arrival; breeding commences later after arrival). Conditions along the migratory route and at stopover points are more important among capital breeders.

For short-distance migrants , we expect earlier breeding and later departure (no great distance), range expansion northward (increasing stewardship), greater increases in range expansion and abundance among species whose habitats farther south are deteriorating (e.g., increasing aridity should affect species seeking moist or mesic habitats), increasing numbers of resident birds (especially among those migrating shorter distances), earlier clutch initiation, extension of the breeding season among species capable of multiple broods, thus increased abundance (greater stewardship). The potential for a mismatch between phenology and the food resource is increased over previous groups, because regional cues may not be accurate. Consequences of mismatch should appear in reproductive measures. The constraints noted earlier (food habits, body size, capacity for multiple broods) apply. As well, the potential differences among capital and income breeders could be apparent.

Among species whose nesting historically has been restricted to the north of province, some may show increases in abundance as conditions farther north deteriorate more than they do in British Columbia. That is, there is potential for the province to accumulate greater stewardship responsibility from the north as well as the south.

Analyses of meteorological data in Europe suggest that local temperatures appear to reflect relatively large regions (Heino 1994; Sokolov *et al*. 1998); nonetheless British Columbia's ecoprovinces show different temperature responses (B.C. Ministry of Water, Land and Air Protection 2002). Evaluations of trends versus climate data may thus show a stronger response to ENSO than to temperature in ecoprovinces.

*Long-distance migrants*
We define long-distance migrants as having a significant portion of the wintering population > 1000 km south of the 49th parallel, and less than 4500 km (about 38° to 8°N or to the southern end of Central America). For this group, changes along migration routes and stopover points become increasingly influential, and distinctions between capital and income breeders should be greater. As well, the time and energy for molt prior to migration south may become a constraint. Departure times from winter and summer ranges are more likely to be under endogenous control or photoperiod (Berthold 1996; Gwinner 1986).

We expect little change in arrival dates, although northernmost, long-distance migrators are potentially susceptible to the El Niño Southern Oscillation. We also expect no change in departure dates, with the potential exception of income breeders that are able to breed earlier. Early initiation of clutches is expected primarily among income breeders, because capital breeders arrive ready to breed. The possibility of a mismatch between phenology of the food resources is increased because regional cues on wintering grounds may misrepresent conditions on the breeding grounds. The constraints noted earlier (food habits, body size, capacity for multiple broods) still apply, but may have less influence because molt and the migration distance dominate.

The potential for range expansion in British Columbia is considerable because many returnees from the wintering grounds are young birds with little affinity for natal areas. Among species whose nesting has been restricted to northern portions of province, there is the potential for increases in abundance as conditions farther north deteriorate more than they have in British Columbia.

*Very long-distance migrants*
We define very long-distance migrants as having a significant portion of the wintering population greater than 4,500 km south of the 49th parallel, into South America. Within this group, changes along migration routes and stopovers become more important, as do the time and resources for pre-migratory molt and the distinction between income and capital breeders. We expect relatively firm endogenous or photoperiod control over migration and possibly molt.

Expectations are similar to those for long-distance migrants, with the exception that the potential for mismatch with phenology of food resource is greater still, and there should be even less flexibility in arrival and departure dates. The potential for range expansion persists because, again, many returnees are young with relatively little affinity for natal areas. As well the potential remains for species whose nesting has been restricted to the north of province to show potential increases in abundance as conditions farther north deteriorate.

Reponses of two other distinct but diverse groups of birds should be considered because their responses could alter British Columbia's stewardship responsibilities.

*Over-winter only*
These are species of which a considerable number winter in the province, but do not breed here. Example species include Rough-legged Hawk, Dunlin, Black Turnstone, and Surfbird.. As conditions deteriorate to the south of the province, British Columbia could become the wintering grounds for increased numbers.

*Southern end of the range in northern British Columbia*
Some species historically have bred primarily north of the province, but the southern portion of their range extends into the province. Examples include Pacific Loon, Trumpeter Swan, Baird's Sandpiper, and Northern Shrike. Current evidence suggests that climate change is more dramatic in the north. If conditions become unfavourable north of British Columbia, we could see greater abundance of these species within the province.

### *Example Species and Predictions*

Because of the inherent variation within and among bird populations we also expect considerable variability in response (Møller and Merila 2004). We thus expect our predictions from the general model to apply to significant portions of any group, rather than to all species within a group. Our sample of species is limited. We noted earlier that to permit entry of more than a century of observations we had to restrict our analyses to only a few species. Nonetheless, we believe it is insightful to provide candidate examples of each group, and to summarize findings we attained when analyzing members of those groups.

**Resident species**

*Example species:*

Resident single brooders: Common Raven, Gray Jay, Bald Eagle, Red-tailed Hawk, Great Horned Owl

Resident variable brooders: Stellar's Jay, Song Sparrow, American Robin

Resident, British Columbia is northern edge of range: Hutton's Vireo, House Finch

*Predictions tested to date:*

None.

**Partial Migrants**

*Example species:*

Single brooders: Common Loon, Surf Scoter (mostly migrating through), White-winged Scoter, Barrow's Goldeneye

Variable brooders: Yellow-rumped Warbler (Myrtle race), Dark-eyed Junco

*Predictions tested to date:*

Earlier arrival: COLO and SUSC are arriving at inland areas earlier as predicted; WWSC is not. COLO is arriving at inland lakes about 7.6 days/decade earlier (Figure 1).

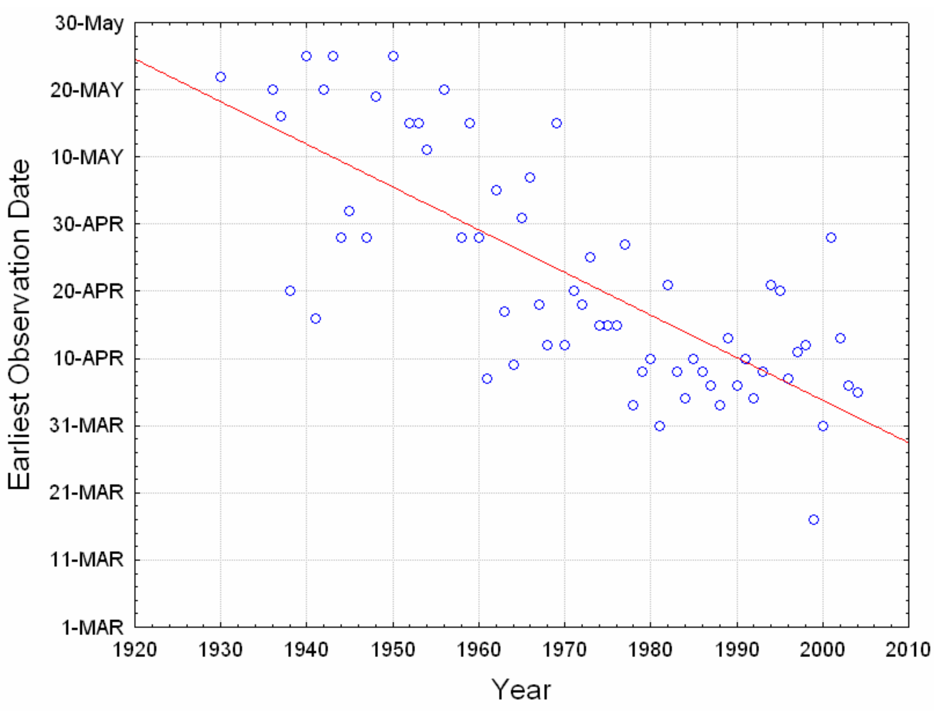


**Figure 1**. Earliest observation dates of Common Loons in the central and northern interior of British Columbia. b = -0.76 days/year, r2 = 0.57, Sy.x = 11.3, p < 0.001; n = 64.

The Common Loon is arriving at inland lakes about 7.6 days/decade earlier.

Earlier departure: COLO is departing inland areas later as predicted; SUSC and WWSC show insignificant trends to depart later. The more extensive COLO data reveal behaviour differs among lakes.

Range expansion: COLO, SUSC, and WWSC already occurred throughout province and show only modest expansion of range (greater stewardship).

Abundance: Relative density of COLO, SUSC, and WWSC has shifted northward as predicted.

Reproduction : not yet tested

**Short-distance Migrants**

*Example species:*

Probably three major distinctions: capital and income breeders, food types during breeding, and number of broods.

Single brooders: Eared Grebe, Gadwall, Turkey Vulture, Sandhill Crane (some races), Lewis's Woodpecker, Barn Swallow

Variable brooders: Mountain Bluebird, Western Bluebird, Savannah Sparrow

*Predictions tested to date:*

Earlier arrival: LEWO—cannot distinguish well because of increasing numbers of resident birds; does not arrive earlier in Southern Interior Mountains Ecoprovince; interior SACR arriving earlier as predicted.

Later departure: LEWO—cannot distinguish where over-wintering occurs; slight, insignificant trend to depart later in Southern Interior Mountains; interior SACR departing later as predicted; over-wintering increasing on the coast.

Range expansion: insignificant spatial expansion for LEWO, not as predicted; not evaluated for SACR other than increased over-wintering (greater stewardship). Increased over-wintering: present in SACR and LEWO as predicted (greater stewardship).

Abundance: LEWO shows a significant shift in relative density northward as predicted. SACR has increased on the southwest coast where it now over-winters.

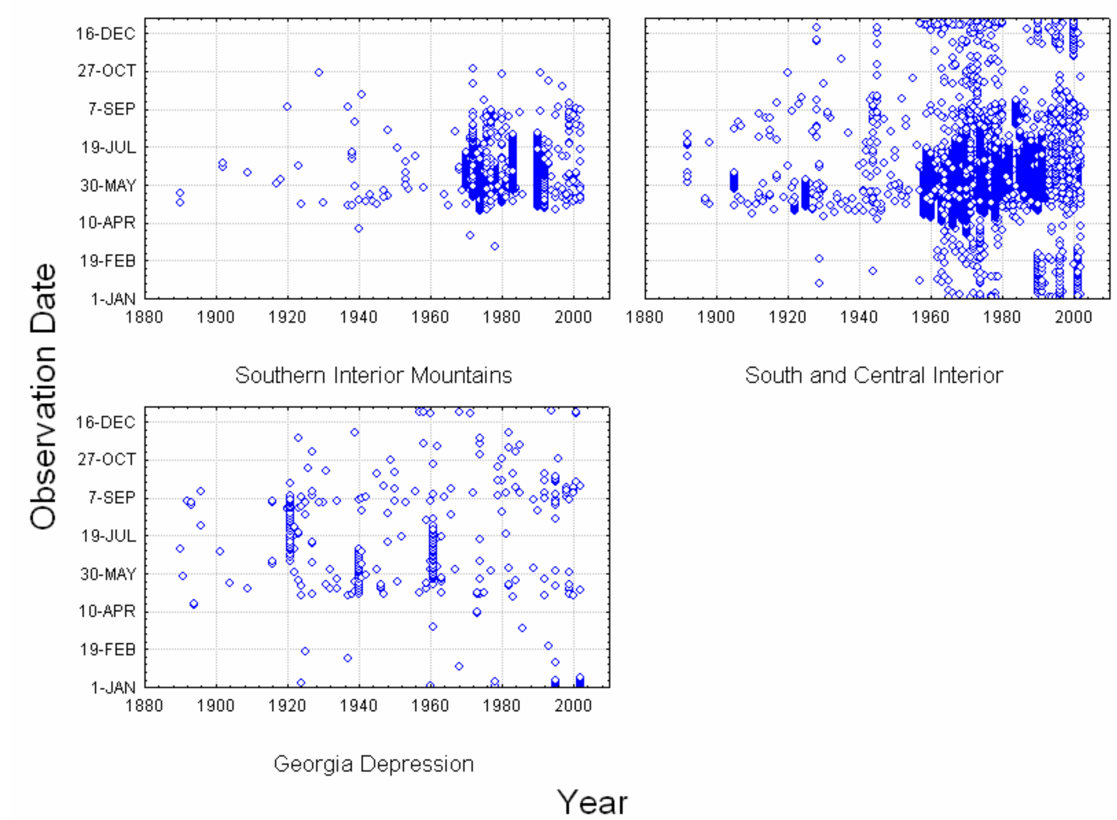


**Figure 2**. Dates of observation of Lewis's Woodpecker in ecoprovinces of British Columbia for the period 1890–2003 a) Southern Interior Mountains (n = 1103), b) South and Central Interior (n = 6131), c) Georgia Depression (n = 387).

Figure 2 illustrates a dramatic increase in over-wintering Lewis's Woodpeckers, particularly in the south interior. Although the relative density of the species has shifted significantly northward ($p < 0.001$), the northern edge of the range has moved little and the species appears to be constrained by northern limits of the Interior Douglas-fir and Ponderosa Pine Biogeoclimatic Zones.

Reproduction: LEWO shows a slight tendency to breed later; not as predicted. However, the relative density has shifted greatly northward, so the result is not surprising.

**Long-distance Migrants**

*Example species:*

Single brooders:

Capital breeders: Alder Flycatcher, Western Wood Peewee, Yellow Warbler

Income breeders: Spotted Sandpiper, Eastern Kingbird, Swainson's Thrush, Tree Swallow.

Variable brooders: Willow Flycatcher, Rufus Hummingbird, Lincoln's Sparrow

*Predictions tested to date:*

Earlier arrival: YEWA winters farther north and is arriving earlier; SWTH winters farther south and is not arriving earlier—as predicted (except for coastal populations which are arriving earlier, suggesting more than one migration route).

Later departure: YEWA is departing later; little change in SWTH except in southernmost portion of the province where staying later (Figure 3).

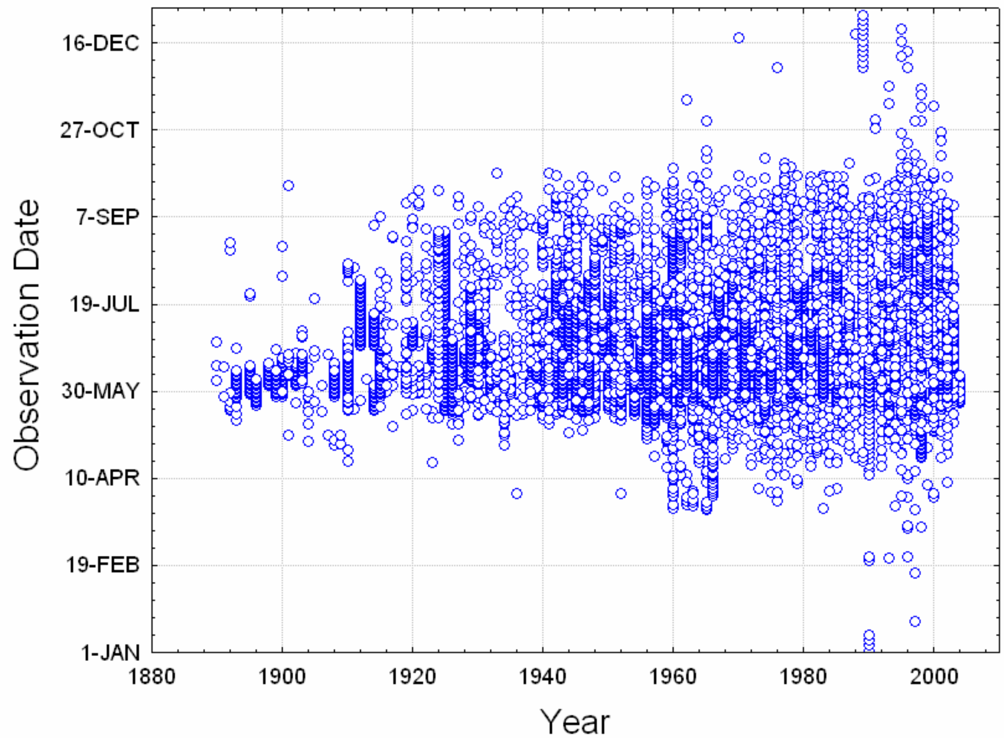


**Figure 3.** Dates of observation of Swainson's Thrush in British Columbia for the period 1890 through 2004 (n = 18,900).

Range expansion: YEWA shows significant northward extensions in both spatial occupancy and relative abundance, as predicted; SWTH migrates farther, shows no northward expansion of range but increased abundance in northern portion of the range. Increased over-wintering: largely absent, as predicted.

Abundance: Greater relative densities in both species, as predicted.

Reproduction: Not yet tested

## Very Long-Distance Migrants

*Example species:* Wilson's Phalarope. Possibly Black Swift.

*Predictions tested to date:*

Earlier arrival: No change was predicted for WIPH and holds for entire population; but coastal and interior populations are behaving differently, with coastal arriving later and leaving earlier implying potential trouble on migration route.

Later departure: Coastal WIPH leaving later; interior WIPH show no change, as predicted.

Range expansion: Occurring northward; prediction equivocal.

Increased over-wintering: Absent, as predicted.

Abundance: Relative density has shifted north; prediction equivocal.

Reproduction: no significant trend in clutch initiation with time (Figure 4); southern populations are breeding earlier than northern populations.

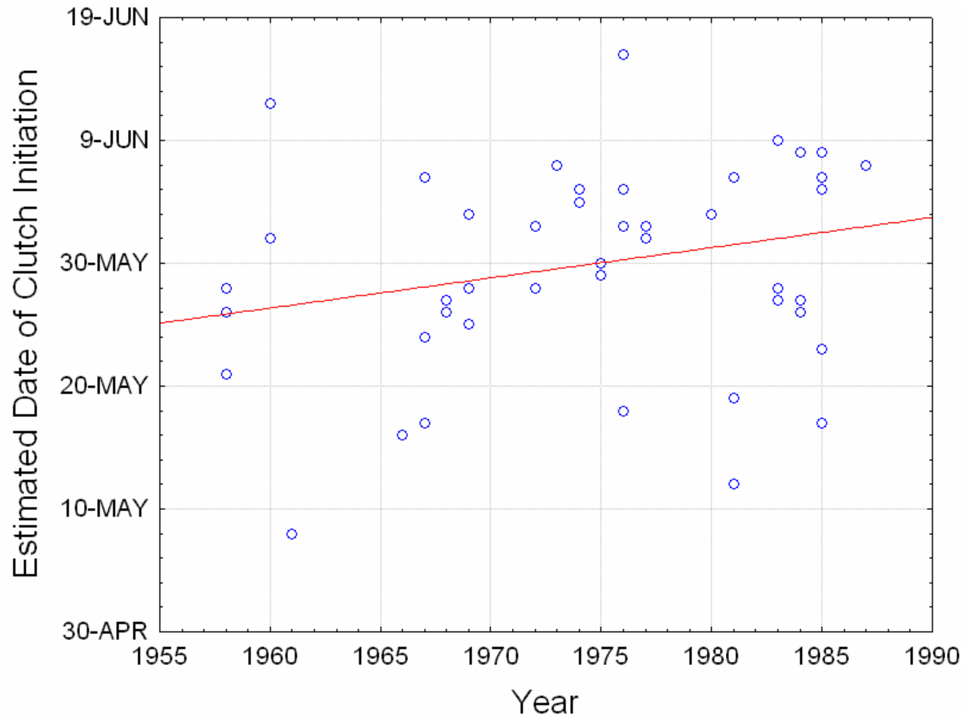


**Figure 4.** Dates of clutch initiation of Wilson's Phalarope in British Columbia over the period 1958 to 1987. Regression of initiation date versus year yields: b = 0.26, n = 49, r2 = 0.07, p = 0.07, Sy.x = 8.14).

Although the trend of clutch initiation over time is currently weak (p = 0.07), it may well reflect events as the species is expanding northward at a significant rate.

### *Conclusions*

Dramatic changes, apparently in response to climate, have occurred in arrival dates, departure dates, over-wintering populations, spatial occupancy, and relative density of those birds evaluated in the province. Many of the responses are as predicted by our general model. We hope to continue our testing with other species and thus gradually "fill out the matrix" of species groups. If the current promise is sustained, we will have a tool to assist management deliberations in the face of climate change.

### *Acknowledgements*

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### *Questions after Fred's Presentation*

Question:

Many of British Columbia's birds migrate to the far south. Do you need to look at the climate changes in Argentina as well to see how climate change is affecting birds?

Response:

Yes, if we want full understanding. We will need to look at what's happening along migration routes as well. Birds that travel through the drier parts of the United States (that are drying faster under changing climate conditions) will be affected on the way north. There are some listed species that we are concerned about, and we have no idea where they winter (e.g., the Black Swift). It is clearly important to have a better understanding of wintering areas.

Question:

What about survivability? Are the populations increasing, decreasing, staying the same?

Response:

Abundance for the species we looked at is increasing so far, but this likely will change. Often it is going to come back to water as a limiting factor. Many wetlands are going to be lost, and this is going to have a huge impact. Another thing that may happen is that those species which can produce more than one brood are going to be able to out-compete the ones who can't.

# 10. Mountain Caribou and Climate Change

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### *Introduction*

This paper is a summary of a presentation delivered at the "Implications of Climate Change in British Columbia's Southern Interior Forests Workshop" organized by the Columbia Mountains Institute in Revelstoke, British Columbia. The presentation begins with general background on mountain caribou, followed by a summary of the habitat relationships of mountain caribou, an exploration of some of the potential implications of climate change on mountain caribou habitat elements, and a discussion of how the cumulative effects of other human activities may influence the impacts of climate change.

### *Background on Mountain Caribou*

Mountain caribou are an ecotype of woodland caribou that inhabit the moist and wet mountains of interior British Columbia (MCTAC 2002). They are distinguished from other woodland caribou by a number of characteristics:

- Geographic range: Their occurrence is restricted to the wet mountainous regions of south/central British Columbia - "interior rainforest" (see Figure 1).
- Dependence on arboreal lichens: The primary forage source in fall and winter for mountain caribou is arboreal lichens (i.e., lichens that grow on trees, primarily *Bryoria spp*. and secondarily *Alectoria spp.*).
- Herd size: Dispersion as small groups or individuals, in contrast to some barren ground caribou that seasonally congregate in large herds.
- Habitat: Dependence on large patches of old forest to isolate themselves from other ungulates and predators.
- Seasonal elevational migrations: In response to snow depth, snow consolidation, and resulting forage availability.

Although densities likely varied, historically mountain caribou occupied a continuous range from northern Washington and Idaho to north of Prince George. Over the past 100 years the distribution and total numbers of mountain caribou have decreased dramatically due to increasing impacts of resource development and backcountry use. This has lead to their designation as a species at risk, both federally and provincially in Canada, and federally in the United States. At present their range has been reduced to 18 isolated subpopulations. Total numbers have continued declining over the past few years, to less than 1,700 in 2002. If this trend of human conflicts and decreasing numbers continues, some of the subpopulations will likely disappear over the next few decades, regardless of climate change (MCTAC 2002 and Wittmer *et al*. 2005).

To examine the potential impacts of climate change on mountain caribou, it is necessary to consider the specific habitat relationships of caribou and how climate change may impact those habitat relationships. Mountain caribou have an annual life cycle which is composed of four principal seasons, each of which is characterized by differing habitat use and foraging patterns, as described in Table 1.

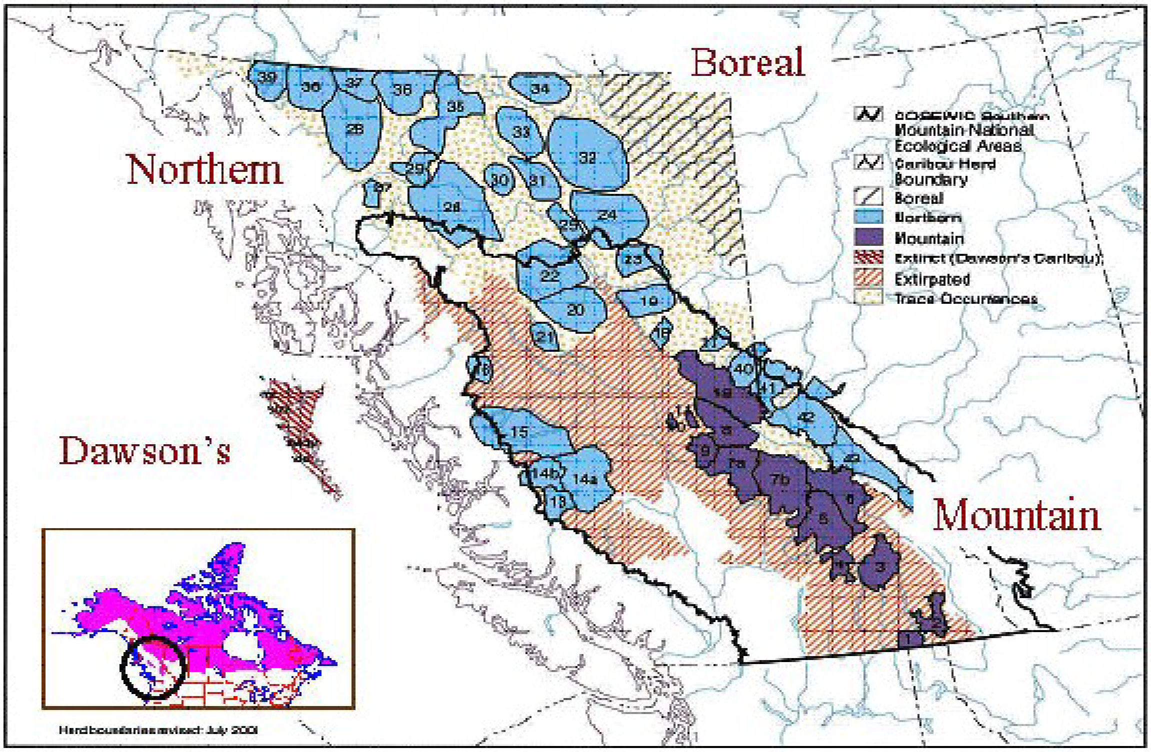


**Figure 1.** Distribution of woodland caribou in British Columbia (adapted from MCTAC 2002).

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**Table 1.** Mountain Caribou Seasonal Cycle

| Season | Spring | Summer | Early Winter | Late Winter |
|---|---|---|---|---|
| **Approx. Dates** | Mid-April to May | June to October | November to mid-January | Mid-January to mid-April |
| **Initiation Event** | Mid- to low elevation snowmelt and herbaceous vegetation development | High elevation snowmelt and vegetation development | High elevation snow depths that limit access to herbaceous forage | Sufficient high elevation snow depths and consolidation to provide access to arboreal lichens |
| **Habitat Use** | Upper valleys to low elevations—early snowmelt areas (south-facing openings, wet meadows) in large patches of old forest | Subalpine—alpine; remote areas; large patches of old forest; favouring cooler environments | Mid- to low elevation areas with large patches of old forest (when large patches unavailable, smaller patches); in some areas windswept open ridges | Subalpine—alpine parkland; open stands of old subalpine fir forest |
| **Forage Utilization** | Newly flushed herbs and shrubs (grasses, sedges, flowering plants, some shrubs) | Shrubs and herbs | Evergreen shrubs (e.g., *Pachistima myrsinites, Vaccinium scoparium*); ground lichens in windswept areas; arboreal lichens via litterfall and blowdown (mainly *Bryoria spp*. and *Alectoria spp.*) | Arboreal lichens (mainly *Bryoria spp*.) |
| **Predation and other mortality factors** | Avoidance of predators by remaining in smaller openings in large patches of old forest | Avoidance of predators by moving to remote high elevation alpine areas and/or large patches of old forest | Avoidance of predators by remaining in large patches of old forest and avoiding areas where other ungulates congregate | Separation from most predators due to snow depth; risk from snow avalanches |
| **Critical Climatic Factors** | Snow depth and onset of spring snowmelt | Summer mean and maximum temperatures; growing season precipitation | Snow depths within these habitats; winds and snow distribution on ridge crests; wind and wet snow events creating windfall and branch breakage; snow interception by forest canopies | Snow depths—average annual and variability between years; snow consolidation |

The risks to mountain caribou survival can be simplified into three main components:

- Adequate access to suitable habitat that provides life requisites
- Displacement into poor quality habitat
- Exposure to mortality

High quality habitat can generally be described as habitat that provides adequate access to life requisites such as forage, water, and a suitable thermal regime (i.e., acceptable temperatures); the ability to move between seasonal habitats with sustainable energy costs (e.g., moderate to flat slopes); and security from predators sufficient to maintain sustainable population numbers. In general, high quality mountain caribou habitat consists of large patches of old forest found at mid- to high elevations (see Table 1). Although this varies somewhat between subpopulations, seasonally, mountain caribou generally are found at higher elevations in the late winter and summer, moving to mid- and lower elevation forests in the spring and early winter.

The open high elevation forests used in late winter are dominated by subalpine fir or whitebark pine with abundant arboreal lichens that occur low enough on the trees to allow caribou to access them while standing on consolidated snowpacks in the late winter. High quality spring habitats consist of low to mid-elevation forests that become snow-free first, openings on mid- to high elevation south-facing slopes and/or wet meadows within large tracts of old forest. The main factors for selecting these habitats are the production of abundant herbaceous growth, an early snow-free date, and isolation of these sites from similar areas that may have higher numbers of other ungulates and their predators. Summer habitats are high elevation forests and alpine areas providing adequate herbaceous and shrub forage. Low to upper elevation forests used in early winter are generally large patches of old cedar hemlock, Douglas-fir, subalpine fir, and/or Engelmann spruce with abundant arboreal lichens and/or an understorey of suitable shrubs for early winter forage. These forests must provide sufficient canopy closure for effective snow interception, ensuring shrubs are accessible. Arboreal lichens available on windfalls or fallen tree branches are also important early winter food sources.

Caribou select for suitable habitats at multiple scales. At regional or landscape scales caribou are selecting for general vegetation zones or landscape features such as: higher elevations with Interior Cedar-Hemlock, Engelmann Spruce–Subalpine Fir, and Parkland forest zones; mountainous, but generally not rugged terrain; and broad expanses of unfragmented forests. At the stand and site levels, caribou are selecting for open stand structures associated with old forests, abundance of arboreal lichens, and low shrub coverages providing good visibility for predator avoidance. During summer, caribou may be favouring cooler sites at various scales to assist with thermal regulation by selecting for higher elevations, northerly aspects, and closed canopy stands. Mountain caribou also tend to select gentle to moderate slopes, presumably to minimize energetic costs of movement between suitable habitats.

A number of species have been found to prey on mountain caribou, including wolves, cougars, wolverines, grizzly bears, and black bears. Other smaller predators (e.g., lynx, bobcat, coyotes, and eagles) may also prey on caribou calves, but little information is available about their roles on population regulation. Generally caribou are not the primary prey for these predators, but rather a secondary prey used opportunistically when encountered. Therefore the relative abundance and distribution of the primary prey species (mainly deer, moose, and elk) are important to predation rates for mountain caribou. Mountain caribou mortality also results from other secondary factors, including falls and snow avalanches, vehicle collisions, and hunting (only illegal hunting at present).

### *Potential Climate Change Impacts*

Climate change has the potential to directly impact mountain caribou by modifying a number of factors that affect the abundance, distribution, and quality of caribou habitat, the ability of caribou to move between seasonal habitats, and/or effectively avoid predation. Climate change may also have indirect impacts on caribou by affecting other external factors that are important to caribou survival. The impacts will occur at broad regional scales, as well as landscape and stand levels. Because of the close ties between caribou movement and seasonal snow conditions, seasonal shifts in climatic variables, particularly related to snow conditions, are also significant.

Climate change modelling has predicted some potentially dramatic shifts in biogeoclimatic zonation within the present range of mountain caribou (see Figure 2). The projections for 2055 indicate a significant decrease in alpine and parkland subzones, and an increase in the Interior Cedar-Hemlock zone. The potential loss of some areas of summer and late winter habitat may be of concern. Assuming that many of the Engelmann Spruce–Subalpine Fir zone stands moving upslope will continue to be relatively open due to shallow soils and other edaphic factors, this may in part compensate for loss of some parkland areas. However over the longer term, the predictions for 2085 indicate an increase in drier vegetation types at lower elevations, potentially resulting in increases in alternative prey species such as deer, moose, and elk. Assuming that predator species themselves are unaffected by the climate change (a major unknown), predator numbers may increase in response to increasing prey, and thereby create greater predation pressure on caribou.

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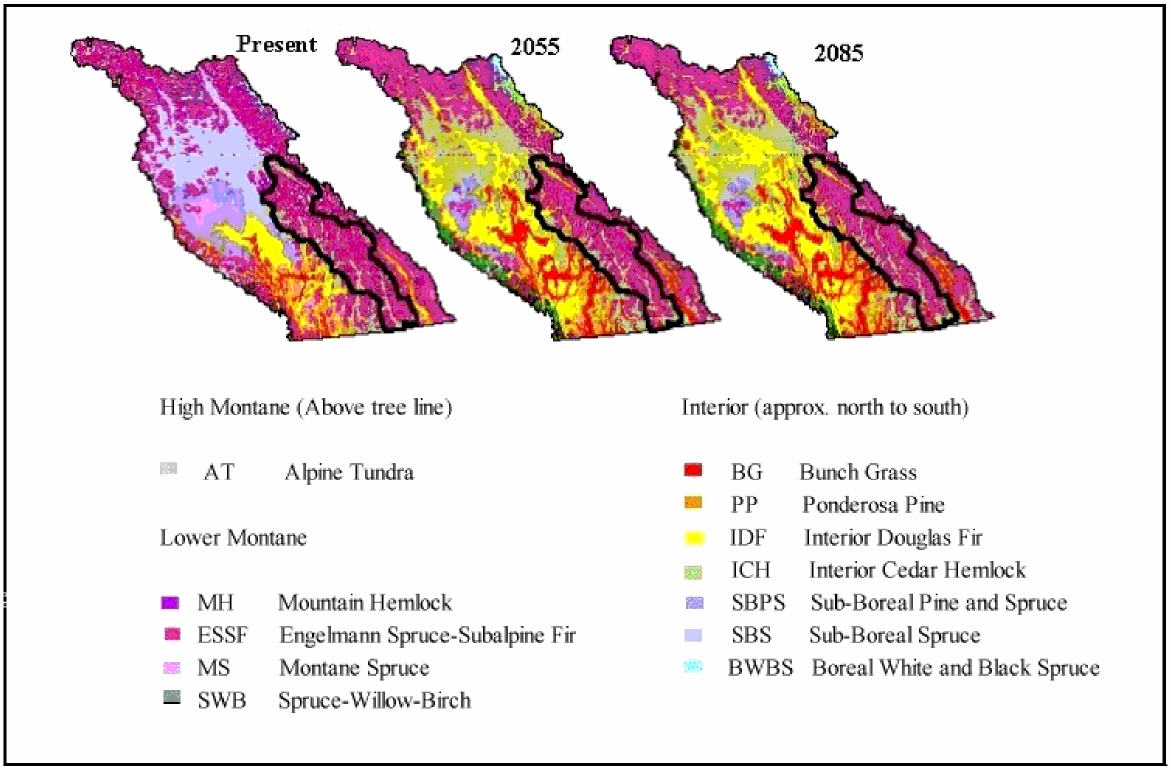


**Figure 2.** Projected shifts in biogeoclimatic zones in southeastern British Columbia. Black line indicates the approximate present distribution of mountain caribou. Note the decrease in AT and ESSF and increase in ICH, PP, and IDF (adapted from Hamann and Wang 2005).

If the information was available, one could examine the projected abundance and distribution of individual mountain caribou forage species. As a substitute, Figures 3 and 4 present projected distribution maps for subalpine fir and western red cedar. Within the range of mountain caribou, subalpine fir is loosely correlated with the distribution of the arboreal lichens that mountain caribou depend on, and western red cedar is roughly correlated with the distribution of falsebox, a common early winter forage species. The projected distributions indicate a significant increase in the distribution of western red cedar in the mid-term with a shift up in elevation and northward in the longer term. Subalpine fir distribution tends to shift up in elevation, with long-term decreasing presence in the south and on the drier plateau portions of the present range. However, both tree species maintain significant presence in the area presently occupied by mountain caribou, and their increased distributions to the north may indicate the potential for range expansion for caribou in those northern areas.

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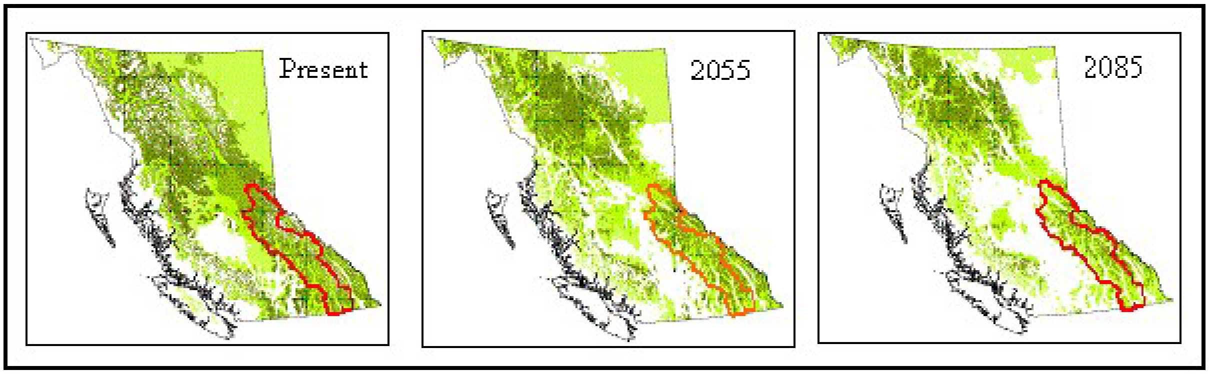


**Figure 3.** Present and future projected range of subalpine fir; darker areas are higher probability of occurrence (adapted from Hamann and Wang 2005).

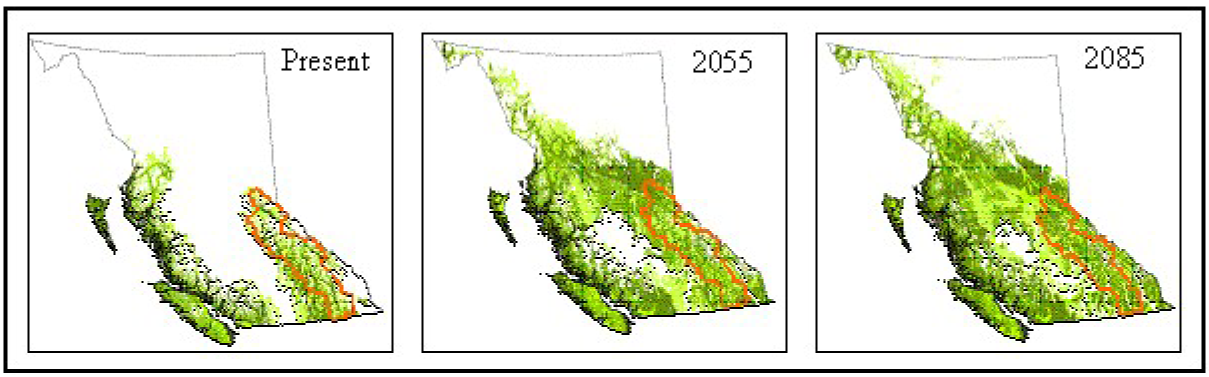


**Figure 4.** Present and future projected range of western red cedar; darker areas are higher probability of occurrence (adapted from Hamann and Wang 2005).

*Continued…*

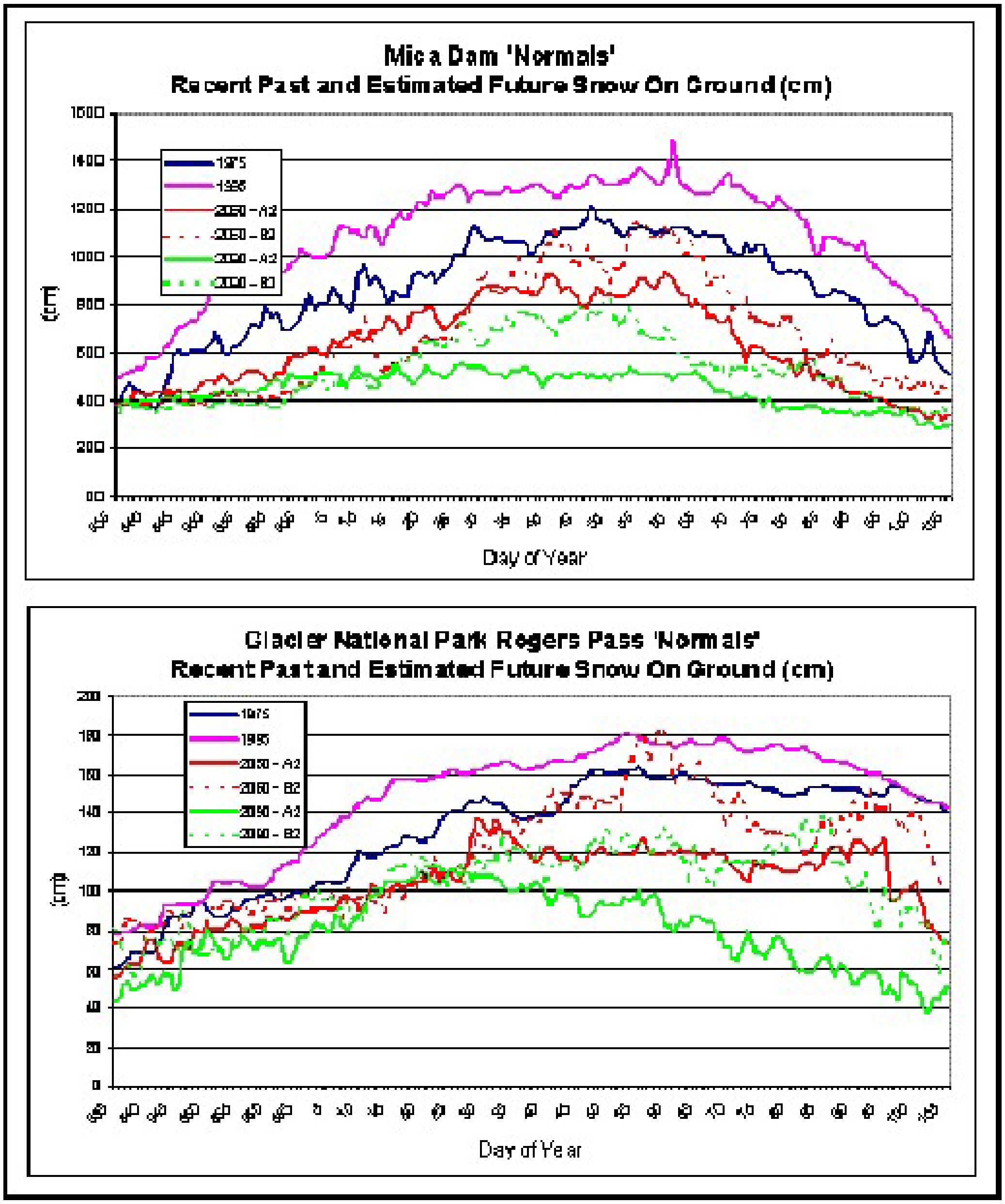


**Figure 5.** Recent past and projected snow depths for Mica Dam and Rogers Pass (December 1 to April 15). Dark blue lines are 1975, purple is 1995, red is projected 2050, and green is projected 2090. The red and green dashed versus solid lines are based on different assumptions regarding green house gas emissions (adapted from Benton, in progress, 2005).

As described in Table 1, the annual cycle for caribou is closely tied to changes in snow depth and consolidation in the snowpack. In general, climate change projections suggest reduced snowpacks and shorter winters, particularly at lower elevations (see Figure 5), but there is little available information on the details of the particular seasonal snow conditions that are most significant to mountain caribou. In addition to changes in total snow accumulation, the timing of early winter accumulations and spring snowmelt, year-to-year variability in snowpack, and the consolidation of the snowpack will have potentially significant impacts on mountain caribou. The depth and timing of the onset of winter snow accumulation affects the availability of early winter forage, while the depth and consolidation of the mid- and late-winter snowpack affects the availability of arboreal lichens during that season.

As shown in Figure 6, year-to-year variation in snow depths alone can have potentially serious effects on arboreal lichen availability. Snowpack depth is significant in determining the height at which arboreal lichens occur on trees and the rate at which lower canopy areas are colonized by lichen, as well as the height caribou are able to access in the winter. Arboreal lichen presence is also affected by factors such as humidity, the presence of lower branches for substrate, stand density, lichen species, and other factors—all of which may be affected by climate change.

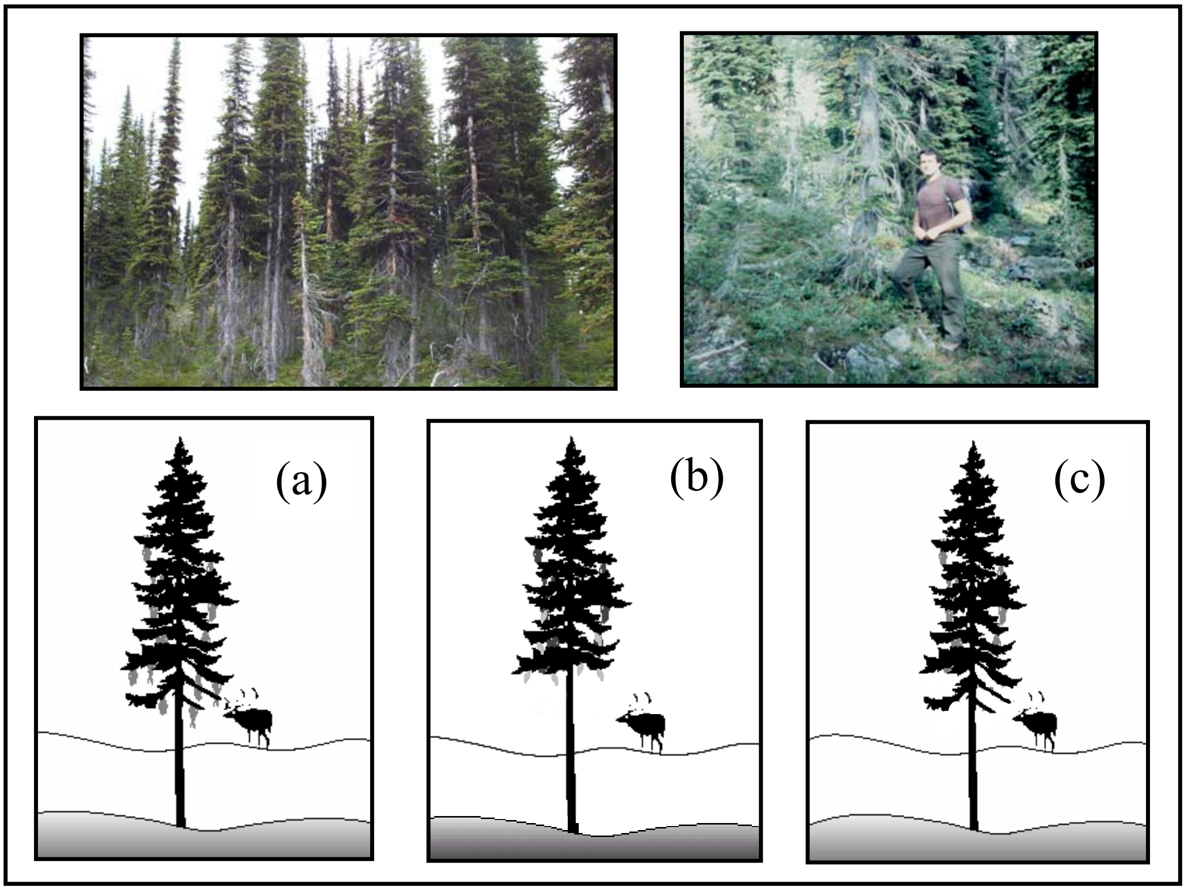


**Figure 6.** The grey lower branches in the photos demonstrate the usual depth of the snowpack, below which few lichens occur. Sketch (a) indicates the ideal situation, where snowpack is consistent year-to-year and arboreal lichens are easily available. Sketch (b) shows the reduced access to arboreal lichens in low-snow years. Sketch (c) shows the reduced access in years immediately following a deep snow year where lichens have died back, effectively moving up the tree in response to the previous deep snow year (adapted from Stevenson *et al*. 2001).

Climate change also has the potential to indirectly impact factors that are important to the survival of mountain caribou. Table 2 provides a few examples of potential indirect impacts.

**Table 2**. A few examples of potential indirect impacts of climate change induced impacts on mountain caribou.

| Climate Change Effects | Potential Indirect Impacts on Mountain Caribou |
|---|---|
| Increased insect and disease attacks on forage species or tree species (e.g., hemlock looper attacks, spruce bark beetle). | Changes to forest patch size and fragmentation, stand structure and ecosystem components lead to changes in forage availability, abundance of alternative prey species, and/or predation rates. |
| Increased occurrence of fire. | Changes to the abundance of young seral forests, forest patch size and fragmentation, stand structure and ecosystem components lead to changes in forage availability, abundance of alternative prey, and/or predation rates. |
| Changes in snow depths, snow consolidation and/or other factors affectthe abundance, distribution and/or predation success of predators. | Changes in predation rates on mountain caribou. |
| Changes in snow depths, snow consolidation, and/or other factors affect the use patterns of winter industrial and recreation activities. | Increased displacement of caribou from high quality habitats resulting in deterioration of animal health and/or an increase in mortality. |
| Increased variability of snowdepths on other ungulate winter ranges results in changes in widely fluctuating populations of alternative prey species. | Changes in predation rates on mountain caribou. |
| Changes to microclimate in forest stands. | Changes in abundance and distribution of arboreal lichens. |

***Uncertainty***

Even these generalized projections of climate change and their potential impacts on mountain caribou carry a significant amount of uncertainty. The climate change projections themselves are highly dependent on assumptions about future human actions, particularly what measures we take to curb our emissions of greenhouse gases and when we take those measures. The projections are also dependent on the configuration of the global climate change models used to make the projections. For localized projections of specific climate variables or ecosystem change, the output of the global models has also been further refined by secondary models, which adds to the uncertainty inherent in the global model projections (e.g., see Hamann and Wang 2005).

Uncertainty also arises from our lack of understanding about how ecosystems themselves will respond to climatic changes. The basic interpretation of the projections for biogeoclimatic zones (BEC) unit shifts is that ecosystems will simply migrate with changes in climate (Figure 7). However, ecosystem response is unlikely to be that simple. Ecosystems are collections of species, each of which has their individual habitat niches. At present, the niches of the species that characterize a BEC unit overlap sufficiently to allow them to form ecosystems within the area occupied by that BEC unit. Although the predicted values of climatic variables are similar in areas projected for that BEC unit in the future, the specific combinations are not identical, and these minor differences may be significant for some species, potentially mountain caribou.

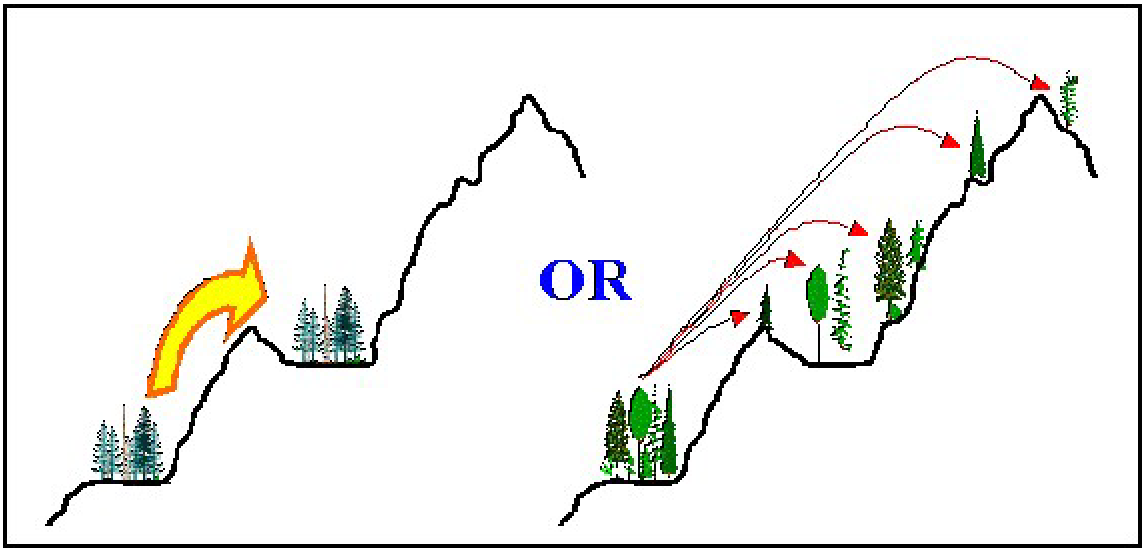


**Figure 7.** Schematic diagram depicting two possible scenarios for ecosystem response to climate change. On the left, an ecosystem simply shifts location with changing climatic conditions, re-establishing a similar ecosystem in a new location. On the right, not all species in the original ecosystem migrate to the same location due to differences in mobility or minor habitat requirements—in this case old ecosystems decay and completely new ecosystems develop.

Topography, geology, and soil conditions may in fact be quite different in the projected new locations for British Columbia BEC zones, leading to further uncertainty that the species assemblages in the new BEC units will be similar to those present today. Some species will drop out and others will be added, creating new inter-species interactions in terms of competition, diseases, and predator-prey relationships. These new interactions will likely further modify the ecosystems.

Some species are fairly mobile because of their physical characteristics, their large home ranges and because they are habitat generalists, or have long-distance seed-dispersal capabilities. Other species are less mobile, having specialized habitats, long reproductive cycles, or short dispersal distances. As climatic conditions change, the more mobile species may readily move to more suitable habitats, while the less mobile species may not be capable of moving at a rate sufficient to keep up with shifting climatic regimes. Therefore, many ecosystems may not move as a single entity, but may rather go through a cycle of ecosystem decay and ecosystem redevelopment, resulting in completely new ecosystems (Figure 7).

This is particularly true of old-growth ecosystems, which may take hundreds or even thousands of years to fully develop. If these types of ecosystems are to persist under projected climate changes, they must somehow cope with fairly significant climate shifts in a matter of decades. Mountain caribou habitats are components of such ecosystems. In addition, for species that select habitat at multiple scales, including mountain caribou, ecosystem decay and re-formation will make it particularly difficult to predict potential outcomes, as stand, landscape, and even regional change all take place simultaneously.

### *Cumulative Impacts*

The ultimate survival of mountain caribou and many other species over the next few decades is likely going to be affected as much by the impacts of human activities as by the impacts of climate change. Mountain caribou populations are already in decline due the cumulative impacts of:

- Habitat destruction and alteration:
    - loss of key habitats, particularly old and mature forests, through extensive historical fires related to railroad and mining uses, and through recent unstoppable wildfires
    - replacement of old and mature forest habitat with young forests by timber harvesting
    - loss of key low elevation habitats and disrupted connectivity by hydro-electric and flood-control dams
    - fragmentation of large, intact patches of old and mature forests by forest harvesting, other development, and roads
- Displacement:
    - resource development activities (e.g., forestry, mining, roads)
    - commercial and non-commercial recreation activities (e.g., snowmobiling, heli-skiing, cat-skiing)
- Direct mortality:
    - hunting (over-hunting in the past and illegal kills in the present)
    - highway and railroad collisions
- Indirect impacts:
    - genetic isolation, by reducing caribou numbers and fragmenting them into isolated subpopulations
    - alteration of predator-prey systems as other ungulates, and their predators, increase in response to the larger area of young forests within caribou habitat, and fragmentation improves alternate prey and predator access to previously isolated caribou habitats

We can amplify the impacts of climate change by continuing to create a broad range of cumulative impacts listed above, or we can choose to reduce those impacts to a minimum by attempting to take further steps to mitigate the projected impacts of climate change. This will require significantly more emphasis on conservation measures and caribou recovery than we are presently employing.

### *Conclusions*

It is impossible to reliably predict the potential impacts of climate change on mountain caribou; however, all information points to an increase in the types and magnitude of risks to the long-term persistence of mountain caribou. There are general indications that the present range of mountain caribou may be reduced in some areas and increased in others. There are indications that the ecosystems in which mountain caribou presently occur are likely to undergo profound changes over the next century. There are also many unknowns. In particular, it is impossible to predict specific changes to the ecosystem components on which mountain caribou presently rely, or the specific changes to those aspects of ecosystems that contribute to caribou mortality (i.e., predation and other causes). It is also difficult to predict the role human activities will continue to play in controlling greenhouse gas emissions or in controlling other human activities that negatively impact caribou survival.

If we are striving to minimize extinctions in the coming decades, especially among old-growth dependent species, we will have to greatly increase the representation and parcel size of our protected area network. Not only do we need to plan for representation of existing ecosystems, but we also need to begin thinking about regional migration corridors and representation of ecosystems under a completely different climatic regime. Doubling or tripling old-growth reserves and stand-level retention may be a good place to start.

It is clear, though, that without human action to curb greenhouse gas emissions and increased efforts to control activities that more directly affect caribou survival (e.g., habitat alteration and displacement) mountain caribou will face growing risks of continued population declines and eventual extinction. However, it should also be kept in mind that caribou have managed to survive the last glacial period, as well as intervening climate changes over the last 10,000 years, some of which may have approached the scale, if not the speed, of those climate changes occurring today.

### *Acknowledgments*

I would like to express my appreciation to the various caribou biologists on the Mountain Caribou Technical Team that was established by the Provincial Species at Risk Recovery Coordination Office. Much of my knowledge of mountain caribou comes from the numerous discussions with them during Technical Team meetings (also special thanks to Bruce McLellan, Trevor Kinley, and Dennis Hamilton for photos). Thanks also goes to Andreas Hamann and Ross Benton for making unpublished information and various illustrations on climate change in southern British Columbia available for use in this report. I would also like to thank the Columbia Mountains Institute for providing financial assistance for the preparation of my presentation and this report, and to Wildsight, Forest Ethics, the Northwest Ecosystem Alliance, and WWF Canada for ongoing support for my work on mountain caribou issues. However, I take full responsibility for any mistakes or omissions.

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## 11. Understanding and Predicting the Effects of Climatic Change on Mountain Forest Ecosystems: The CLIMET Project.

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Mountain forest ecosystems are potentially sensitive to climatic shifts because of their topographic complexity and strong environmental gradients. Studying the impacts of climate change on relatively intact mountain protected areas offers the opportunity to better understand the mechanisms of ecological response, and monitor rates of change without the confounding effects of land use/land cover changes that are typical of managed areas.

The CLIMET (Climate Landscape Interactions–Mountain Ecosystem Transect) project focused on a transect of three distinct mountain bioregions, with large mountain national parks as core research sites, from the Pacific Coast to the Rocky Mountains. Glacier, North Cascades, and Olympic National Parks are large, wilderness-dominated parks that reflect a gradient of climatic influences from maritime (Olympic) to continental (Glacier) along the United States–Canada border. In each bioregion, we documented impacts of past climatic variability on glacier mass balance, snowpack water equivalence, hydrological output, forest growth, invasion by trees into subalpine meadows, and frequency and severity of wildfires. At Glacier National Park, for instance, glaciers have been reduced from 150 to 27 during the past 150 years. The largest glaciers now cover less than 27% of the area they previously did and numerous watersheds no longer contain any glaciers.

Patterns of drought or elevated snowfall are associated with the Pacific Decadal Oscillation, a 20- to 30-year period of anomalous sea surface temperatures that affect regional climate patterns over the CLIMET study area. These multi-decadal periods facilitated the expansion of cedar-hemlock forests for several centuries but are now tied to subalpine fir invasion of meadows and alpine tundra. Ecosystem models successfully estimated regional patterns of forest productivity in the three bioregions. Climate scenarios were used with the models to examine spatial variability in water balance as a function of forest response to climatic warming. The greatest effects were at mid-elevation sites, where most of the forests grow and where the increasing human population tends to build new homes. Under this scenario, the potential for increased wildfire hazards to people will grow, but of greater concern, is the amount and predictability of the regional water supply.

### *Questions after Dan's Presentation*

Question:
> Where do you get all of that money?

Response:
> Dan coordinates with other people and forms partnerships with existing interests. He adds value to projects by layering interests and types of research. This benefits the researchers and everyone else. Some of it was just serendipity!

***Web Sites for Dan Fagre's work:***

**US Geological Survey – Global Climate Change: A Focus on Mountain Ecosystems**
http://nrmsc.usgs.gov/research/global.htm
The primary objective of this research program is to understand how US Glacier National Park responds to present climatic variability and other external stressors such as air pollution.

**US Geological Survey – CLIMET**
www.cfr.washington.edu/research.fme/climet/intro.htm
CLIMET stands for Climate-Landscape Interactions on a Mountain Ecosystem Transect. This multidisciplinary research effort is directed by US Geological Survey scientists in Washington and Montana. Studies will determine how mountainous protected areas along a transect from western Washington to western Montana are affected by climatic variability.

In lieu of a text version of his presentation, Dan Fagre offered copies of a CD containing many of his reports on climate change and Glacier National Park (Montana) and the CLIMET project. Copies are available from Dan upon request.

## 12. Questions at the Start of Day Two

*At the start of the second day of the workshop, a short question-and-answer period was held to address questions from the previous day.*

Question:

With respect to the spatial variation between net primary production and climate variability: Has anyone considered the specific adaptation of specific species to that?

Response:

Dan Fagre: There are challenges with multiple scales to work at. For example, consider mountain hemlock. As a seedling, it is affected by variation in snow depth. There are definitely differences if looking at habitat scale—the scale at which animals have to integrate changes through time. We have not done this at the biocontinent scale, although we have considered it. There are limits to the computational abilities of current computers. In the computer, on parallel processors, the fire-spread model goes slower than real fire on the landscape.

Richard Hebda: Balance subspecies or ecotypic responses differently.

Question:

One thing that did not get stressed yesterday: Climate change and the adaptability of the forest to move and to change to new species mix. One of the predictions stopped at about 2080. But, many old-growth dependent species, both plant and animal, only start to show up when the forest is 100 years old. How do we adapt to that need as we move into the future?

Response:

Richard Hebda: Conservatively the return to ecological stability takes 100–200 years. Protection should be enshrined in covenants. You need to build time into the understanding of ecological processes. You don't say you need X, you say you need in place the process that will lead to X in time (as faced in Burns Bog). Ask: 'What are the key ecological requirements of the ecosystem?' Identify the essential ecosystem characteristics and processes. Get those working and ensure that the standards and measures for them are in place, and follow through for as long as it takes to get the processes working. No point in investing huge amounts of time and energy for a species if the framework isn't there. This means that things like rare species may fall by the wayside. You can spend large amounts of money on one species, but better to move a level up, and focus on processes first.

## 13. Visualizing Climate Change Scenarios

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***Abstract***

The climate is changing; it has in the past and will continue into the future. We have some tools available that let us look at some of those possible future climates in the form of Global Climate Models (GCMs) and, more recently, Regional Climate Models (RCMs).

GCMs divide the globe into large grids ranging from about $2^o$–$4^o$ (~ 250 km to 450 km on a side) in latitude and longitude while RCM grids are about finer resolution (~45 km on a side) and run within the GCM data bounds. Both are available with monthly and daily data. With increasing computing technology, the data limits are being reduced, but these data are still quite coarse for the complex terrain of British Columbia. Downscaling and data visualization methods make the GCM outputs more useful for researchers and planners.

***Recommended Web Sites for Visualizing Climate Change:***

*Global and Regional Views*
GCMs: Canadian Climate Impacts Scenarios
www.cics.uvic.ca/scenarios/data

GCMs: Intergovernmental Panel on Climate Change
http://ipcc-ddc.cru.uea.ac.uk/java/visualisation.html

Canadian RCMs: Canadian Centre for Climate Modelling and Analysis
www.cccma.ec.gc.ca/diagnostics/crcm/crcm_st.shtml

*Some pre-downscaled data*

Canadian GCM1 Visualization for British Columbia
(Pacific Forestry Centre/Canadian Forest Service/Natural Resources Canada web site)
www.pfc.cfs.nrcan.gc.ca/climate/change/index_e.html

Ross also recommended sites with free software that would allow researchers to downscale or manipulate climate data themselves.

The following graphics illustrate visualizations, at different scales, that are readily available on the internet.

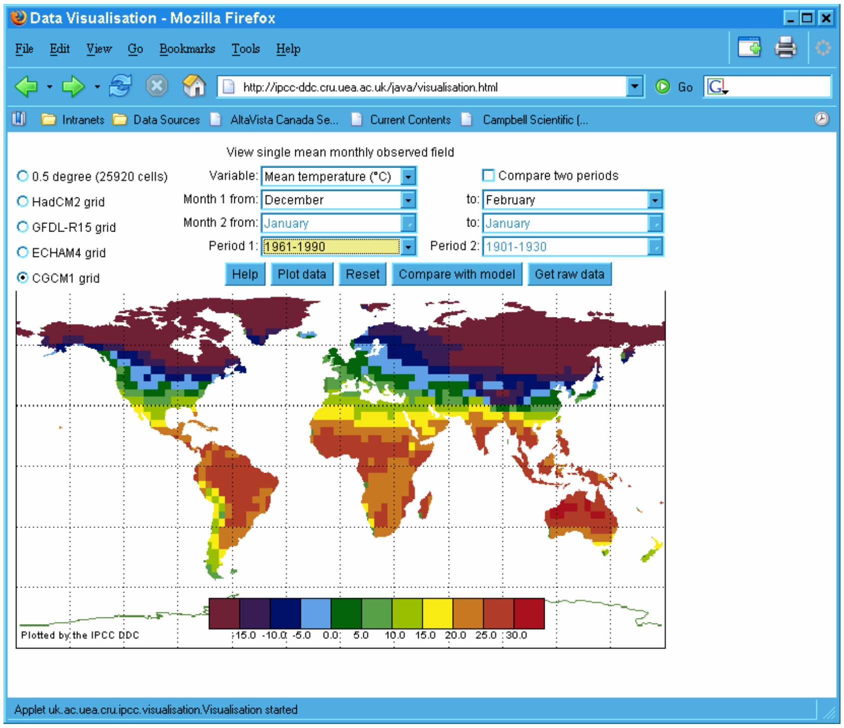


**Figure 1.** Global Climate Model visualization taken from the web site of the Intergovernmental Panel on Climate Change.
http://ipcc-ddc.cru.uea.uk/java/visualization.html

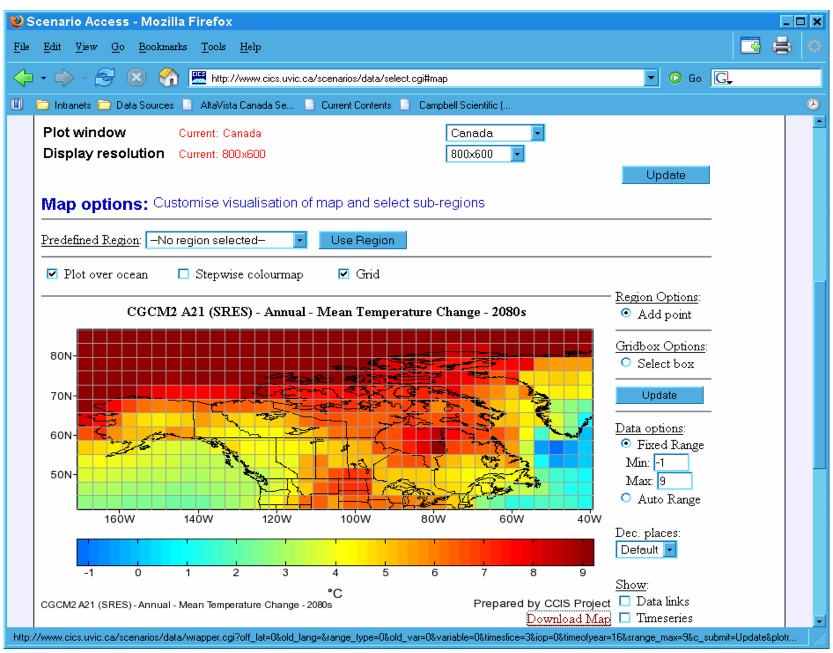


**Figure 2.** National view of the Global Climate Model, as viewed on the Canadian Institute for Climate Studies web site, www.cics.uvic.ca/scenarios/data/select.cgi#map

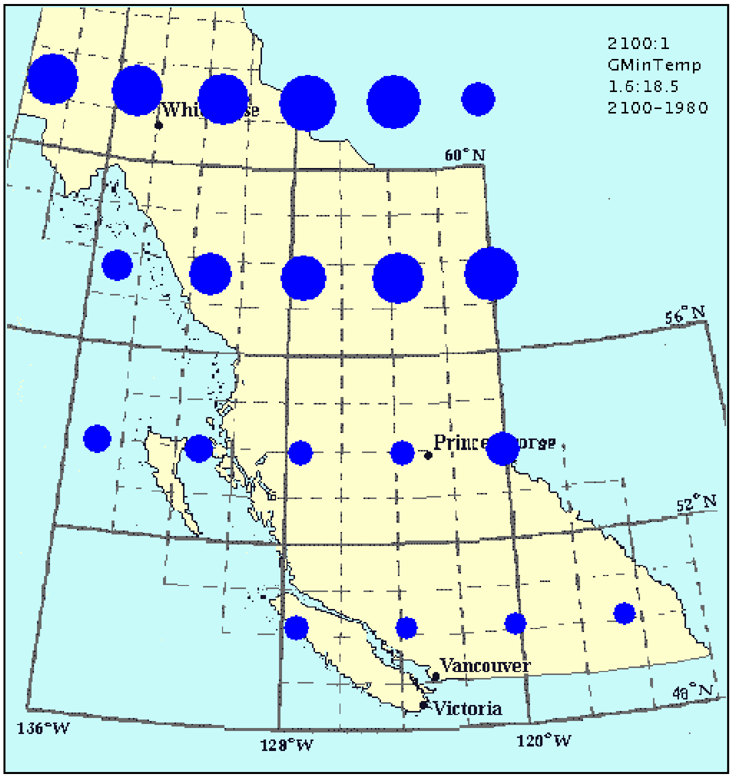


**Figure 3.** Example from the Pacific Forestry Centre's downscaled information (run for: January, 2100: Greenhouse Gas Run 1.3 m Minimum Air Temperature (C) As Difference From 1980) www.pfc.cfs.nrcan.gc.ca/cgi-bin/climate/mappage_e.pl

## 14. Climate Change and Forest Policy in British Columbia: Challenges and Opportunities

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This presentation examined the federal and provincial initiatives, and the public and political environment, that influence the development of forest policy responses to climate change in British Columbia. It will also identify some of the barriers and opportunities within British Columbia's existing forest policy framework for implementing strategies for climate change adaptation.

The reality of climate change poses a serious threat to British Columbia's forests and forest sector, and the communities that depend upon them. Government will be pressured to respond to those threats but public expectations will likely be ahead of scientific and data certainty—at both regional and local scales. Expectations around when adaptive strategies should be implemented will also likely exceed government's and the forest sector's capacity to respond. These public expectations will be found in various resource management areas, such as water, wildlife, recreation, harvesting and access, silviculture, fire, forest health, and carbon sequestration. Although the policy choices may not be equally well-grounded in science, the issues will represent "hot-buttons" for public debate.

The policy challenge then is to fairly represent and integrate the issues, and to influence forest management decisions within the current results-based legislative framework. Policy analysts will struggle with quantifying climate change risks and describing sustainable adaptation strategies sufficiently well enough to convince politicians that it is necessary to change forest management objectives, regulations and operational plans. Changes may also result in additional costs to government and industry, thus the rationale for action will have to be very clear—and there is nothing clear about climate change (at least when dealing with its impacts over the lifespan of a forest.)

Dale Draper noted that the following documents are key to future policy development:

Weather, Climate and the Future: BC's Plan
http://wlapwww.gov.bc.ca/air/climate/

Moving Forward on Climate Change: A Plan for Honouring our Kyoto Commitment
www.climatechange.gc.ca/kyoto_commitments/

### *Questions after Dale's Presentation*

Question:
There is a trend to transfer policy from public to private. From a policy perspective, will this influence precaution or will the private industry influence the ability to take a precautionary approach?

Response:

You are right in your observations. This is a challenge and government has decided the direction of the day. It's not impossible to address within this framework. We could look at changes to make this better. Whether this will be put into effect, we will have to wait and see. Feedback will come.

Comment from Richard Hebda:

Policy tends to begin to be very specific. In this circumstance, flexibility is going to be key. In terms of thinking about how to approach it, ecological integrity needs to come first and the big picture directives need to be clear. How can we define those clearly, without being too specific? Sometimes government can be too specific. Guidance: Get the big principles right first, rather than a minutia of detail first. Government usually focuses on detail.

Comment from Andreas Hamann:

There are small picture questions from the community.

Comment from Richard Hebda:

Community needs to focus on principles and then they can incorporate that.

Comment from Audience:

Bias in Forest Revitalization Plan is to not reduce timber harvest. Emphasis needs to shift to ecological integrity instead.

Comment from Dale Draper:

Concern: How do we arrive at climate change principles? It is entirely possible within the framework, but it may be difficult to articulate that in our policy.

## 15. Adaptation to Climate Change in Forest Management: Challenges and Responses

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***Abstract***

Future climate change will bring changes in the range that species occur, in forest disturbance, and in forest growth. These changes, in turn, will affect society's ability to use forest resources. We already take account of climate in forest management and utilize many of the activities that will be required to respond to the effects of climate change on forests. However, many forest ecosystems and species will have to adapt autonomously because management can only influence the timing and direction of forest adaptation at selected locations. In general, society will have to adjust to however forests adapt. There are numerous challenges that we need to be address in developing and applying adaptive action. These include revising expectations of forest use, determining research and educational needs, developing forest policies to facilitate adaptation, and determining when to implement responses. It is important to start now assessing forest vulnerability to climate change and developing adaptation strategies.

***Introduction***

The climate is changing, but it is always changing. The concern is that future rates of change will be much faster than in the past, and will produce combinations of temperature and precipitation regimes that have no previous analogues and that could have detrimental effects on society (McCarthy *et al*. 2001). Species and ecosystems have responded to past changes in climate. How will the adjustment by species to the future climate affect our ability to use forest resources? Management decisions are based on the assumption that the climate remains relatively stable throughout a forest's life. This may have worked well in the past, but future climate change challenges this assumption. Canada's natural resources and associated industries and communities are vulnerable to climate change and there is a need for the forestry community to be proactive in adapting to climate change (Standing Senate Committee on Agriculture and Forestry 2003, Spittlehouse and Stewart 2003). Adaptive actions reduce the risks by preparing for adverse effects and capitalizing on the benefits. Consideration of climate is part of forest management activities (e.g., fire protection, species selection, culvert design); thus, we already use many of the techniques necessary to adapt to climate change.

In this paper I will review challenges in responding to climate change in forest management (parks, wilderness areas, and the timber harvest land base) and present some options for adaptation. An extensive review of potential adaptive actions in forestry can be found in Spittlehouse and Stewart (2003).

***Adapting to Climate Change—Challenges***

Adaptive actions decrease the vulnerability of a system (organism, ecosystem, company, or community) to climate change. Vulnerability is the degree to which a system is susceptible to or unable to cope with climate change (Smit and Pilifosova 2002). The vulnerability of forests and their users depends on a range of factors (Stewart *et al*. 1999, Dale *et al*. 2001, Hansen *et al*. 2001, Davidson *et al*.

2003). Internal factors include sensitivity to climate at an individual and population level, fecundity, life span, habitat requirements and distribution, entrenched societal values and land use, existing forest policy, and the adaptive capacity of the system. External factors include the magnitude and rate of climate change; frequency, timing, and size of disturbances (e.g., fire, insects, disease, and harvest); competition by systems better adapted to the new climate; and barriers to movement. Systems vary in their vulnerability to change and what may be detrimental to one system could be beneficial to another. Consequently, an important component of the process of adapting to climate change will be a balancing of different values.

Although forest ecosystems will adapt autonomously, their importance to society means that we will need to influence the direction and timing of this adaptation at some locations. There are numerous challenges involved in adaptation, not the least of which is the uncertainty in the magnitude and timing of future climate change and how the forests will respond. This is compounded by the uncertainty in the future markets for our forest resources and global competition (Perez-Garcia *et al*. 2002). Consequently, some people may view responding as a greater risk than doing nothing, that adaptation is not a feasible option at present, and that we may have difficulty finding the resources to fund adaptation to climate change (Burton *et al*. 2002).

The size of the forested land base in British Columbia means that much of the forest will have to adjust without human intervention. There are 38 million ha in the non-timber harvest land base (parks, wilderness areas, and areas with operational constraints) where the main management activities are fire protection, conservation, and infrastructure maintenance. The 24 million ha timber harvest land base is harvested at ≈0.2 million ha per year. Consequently, we will be able to assist forest adaptation on only a small part of the land base at a relatively slow rate. This is likely to be focused on the major commercial tree species and perhaps a few animal species, while the majority of forest plants and animals will have to adapt as best they can.

There are institutional and policy barriers to responding to climate change. For example, seed planting zones and other reforestation standards and guidelines are designed for the current climate regime. There are no requirements for adaptation strategies in forest management plans, nor are there guidelines and experienced personnel to aid such activities. Is the management style of minimum intervention appropriate in the future for parks and wilderness areas (Scott *et al*. 2002)? There are many stakeholders with different needs supplied by forests and different vulnerabilities to climate change. This could mean that, in some areas, adaptation to reduce the vulnerability of resources such as water quality and quantity and biological conservation become the highest priority (Noss 2001).

How will existing forests respond to the changing climate? Most of the wood that will be harvested in the next 50 or more years will come from trees that are already growing or will be planted in the next 10 years. Will productivity increase or decrease and will there be changes in wood quality? Will disturbance by fire and insects become more prevalent leading to salvaged wood being a greater amount of the harvest? How will weather-dependent forest operations such as harvesting be affected?

A changing climate means that the appropriate provenances or species for a site would change. How much change needs to take place before we can safely change the planting stock? Furthermore, because the climate will likely continue to change over the life of the stand, for which particular future climate regime should the planting stock be selected? Should we be choosing species or provenances that can grow adequately over a wide climatic range and do we need new regeneration strategies (Ledig and Kitzmiller 1992)?

***Adapting to Climate Change—Responses***

Although we do not have a clear view of the future climate and future forest, nor of the vulnerability of species and society, it is critical to begin the process of developing adaptation strategies now. Adaptation to climate change in forest management requires a planned response well in advance of the impacts of climate change. First, we need to increase the awareness and education within the forest community about adaptation to climate change. Then, we need to establish objectives for the future forest under climate change. The debate is about values and how society wishes to use its forest resources. Science can help society achieve these objectives—but it does not define them.

Vulnerability assessments of forest ecosystems, forest communities, and society are the next step. Risk analysis tools can be used in planning present and future cost-effective adaptive actions. Adaptation options must include the ability to incorporate new knowledge about the future climate and forest vulnerability as they are developed. We will need to monitor the state of the forest to identify when thresholds for intervention are reached and manage the forest to reduce vulnerability and enhance recovery.

Many of the adaptation activities proposed in the literature are currently part of forest management (Spittlehouse and Stewart 2003). They can be grouped into three categories: adaptation of the forest (e.g., species selection, stand management); adaptation to the forest (e.g., change rotation age, use more salvage wood); and societal adaptation (e.g., forest policy to encourage adaptation, revision of conservation objectives). Table 1 shows how different activities are required for different components of the land base described in the previous section.

*Continued…*

**Table 1.** Options for adaptive actions on forested land. For a more extensive list of options and reference material see Spittlehouse and Stewart (2003).

| **Non-timber harvest land (Parks, wilderness areas, and areas with operational constraints)** | **Timber harvest land (Timber supply lands for next 50–100 years)** | **Timber harvest land (Land requiring reforestation after future harvest)** |
| --- | --- | --- |
| • Identify new areas for conservation<br>• Fire protection of high value areas, including fireproofing of communities<br>• Conserving biodiversity and maintaining connectivity<br>• Revise conservation objectives<br>• Infrastructure maintenance (road rehabilitation, culvert upgrades)<br>• Changes in recreational use | • Stand management such as thinning and disease and insect control<br>• Fire protection of high value areas including fireproofing of communities<br>• Changes in rotation age and wood quality<br>• Bio-energy and carbon sequestration<br>• Increased priority for the protection of non-fibre resources<br>• Infrastructure maintenance (e.g., road rehabilitation, culvert upgrades) | • Present and future climate based seed transfer zones<br>• Research on provenance and species climate tolerance<br>• Tree breeding<br>• Revise regeneration strategies—mixing provenances, stock and species selection, site preparation<br>• Policies to encourage adaptation |

How and when does the forest community begin the process of adapting to climate change? I believe we need to start now. Asking the questions about how to adapt will help determine:

- objectives for the future forest under climate change;
- research and educational needs;
- vulnerability of forest resources;
- policies to facilitate the implementation of adaptation in forest management; and
- monitoring systems required to identify problems induced by climate change.

### *Conclusions*

Society must accept that climate change is probable and that forests and forest-dependent communities face significant challenges. Planned adaptation will reduce the vulnerability of commercial tree species at selected sites, but many forest species will have to adapt autonomously and society will have to adjust to the result. Until climate change has had sufficient impact to warrant intervention, it is likely that at present there is not much that can be done "on the ground, in the forest." However, it is necessary to start assessing forest vulnerability to climate change and developing adaptation strategies. Sustainable forest management already embodies many of the actions that will be required to respond to the effects of climate change on forests. Climate change adaptation strategies can be viewed as a risk management component of sustainable forest management planning.

***Acknowledgements***

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***Questions after Dave's Presentation:***

Question:

Has anyone looked at managing forests as carbon sinks rather than sources of fibre?

Response:

Yes, it is being looked at it. There are risks, Dale will touch on this.

Question:

There were a lot of generalities in your talk. I was looking for specific details – suggestions, details on how to adjust forest management to respond to climate change. Examples: Mountain pine beetle infestation, recent announcement of one million tax dollars going to the B.C. Ministry of Forests to replant these forests. Given what you've said, what would you suggest planting? Lodgepole to get hit again? Where are you at down there in Victoria?

Response:

Dale will be touching on this. There can only be generalities because we are just getting a handle on this. What you do there is a value judgement; I stay away from that. These are lodgepole pine ecosystems, they like it dry. How we deal with it is a big concern. At the moment, the value is to recover some of that wood before it is lost. We are not sitting there ignoring it.

Question:

Species distribution is somewhat plastic, but the soils aren't. Is anyone thinking about the *capacity* to grow trees on Mount Revelstoke when you are heading farther north or upslope?

Response:

That is recognized. Andreas produced projections, but what will the species actually do? Projections are taken into account for our planning now. Assessments of soil conditions are done. Intervention is going to be key—we won't be doing it without thought.

Comment:

In his experience, when lodgepole pine and jiack pine ecosystems are removed or die, black and white spruce take over. Would this happen in area Dave talked about? Hebda said no, it wouldn't.

Question:

Hardwoods seem more resilient than the softwoods. Any thought of planting hardwoods in this province in terms of climate change adaptation?

Response:

No. But it is something to think about—particularly in a short-term rotation. There are ecological concerns to be considered.

## 16. An Adaptation Planning Framework for Forest Management

Greg McKinnon
Forest Sector Coordinator, Canadian Climate Impacts and Adaptation Research Network, Natural Resources Canada.

Given the apparent vulnerability of forests and the forest sector to climate change, it is prudent that forest and forest-based community managers begin developing adaptive strategies to minimize the risks and maximize the benefits of climate change. Early management approaches to climate change adaptation emphasized “impact assessment” methodologies, where climate change scenarios were identified, biophysical and socio-economic impacts were estimated, and management strategies were developed or assumed. More recently, climate change researchers are suggesting the use of “vulnerability assessment” methodologies, where key system vulnerabilities are first identified, and adaptive strategies are developed and evaluated in the context of existing planning and decision-making processes.

In this presentation, I build on this gradual shift in methodological focus by drawing linkages with practical methods from the general field of environmental risk management. In its broadest sense, risk management refers to the entire process of assessing risks (i.e., vulnerabilities), developing and evaluating strategies, making decisions under uncertainty, and communicating effectively with decision makers and stakeholders. Effective implementation and monitoring using an adaptive management philosophy can also be considered as an integral part of a broad risk-based approach to forest management in the face of climate change.

Greg McKinnon provided a 12-page “primer” entitled

***A Risk-based Approach to Climate Change Adaptation in the Forest Management Sector***

It is included as Appendix One to this document.

## 17. Description of Breakout Group Activity

The purpose of the breakout group session was to allow participants to test the concepts learned in the workshop presentations. On the first day of the workshop, participants were offered the "primer" titled *A Risk-based Approach to Climate Change Adaptation in the Forest Management Sector* (included in this document as Appendix One) and the case studies (included as Appendices Two and Three of this document) as pre-reading for this session.

On the second afternoon of the workshop, participants were divided into four groups. Two groups addressed adaptation to climate change in the context of a protected area, and two groups looked at adaptation for a managed forest. Facilitators led participants through the process of clarifying objectives for the land base, identifying vulnerabilities to climate change, and suggesting strategies to deal with these vulnerabilities.

The breakout groups re-assembled in a plenary session to present their thoughts. Appendix Four summarizes what each group presented.

# Appendices

Appendix One:
A Risk-based Approach to Climate Change Adaptation in the Forest Management Sector

Appendix Two:
Case Study: A Managed Forest under Climate Change—Tembec's Tree Farm License #14

Appendix Three:
Case Study: A Protected Area under Climate Change—Mount Revelstoke National Park

Appendix Four:
Notes from Breakout Groups

Appendix Five:
Highlights from Participants' Evaluation Forms

Appendix Six:
Climate Change Scenarios for Southern British Columbia

Appendix Seven:
Recommended Web Sites

# Appendix One: A Risk-Based Approach to Climate Change Adaptation in the Forest Management Sector

*Provided by Greg McKinnon, Canadian Climate Impacts and Adaptation Network, Natural Resources Canada, Victoria*

*This document was originally prepared by D. Ohlson of Compass Resource Management Ltd., for the workshop "Climate Change and Forests: Making Adaptation a Reality" held in Winnipeg, Manitoba in November 2003. It was modified slightly for the Revelstoke workshop.*

### *Foreword*

This primer serves as an introduction to the breakout sessions of this workshop. The purpose of the breakout sessions is to demonstrate the practical application of vulnerability assessment concepts in the development and evaluation of climate change adaptation strategies in the forest management sector. After an introduction to climate change and the expected effects on forests and their management, workshop participants will apply a flexible planning framework on two forest management case studies.

### *Climate Change*

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 such predicted changes is 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.

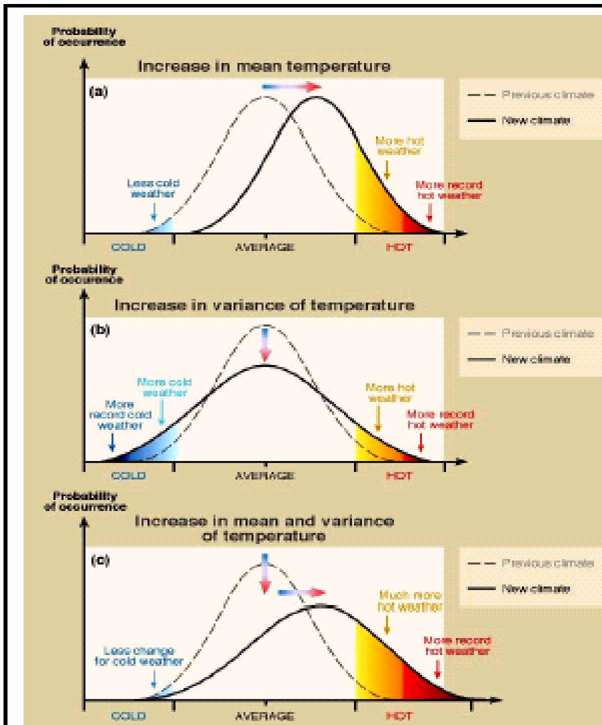


**Figure 1: Schematic diagram showing effects on extreme temperature when (a) the mean increases, (b) the variance increases, and (c) both the mean and variance increase. (Taken from IPCC, 2001b)**

Climate change may manifest itself as a shift in mean conditions, or as changes in the variance and frequency of extremes of climatic variables (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). While uncertainties remain and must be acknowledged, there is growing confidence in the ability of climate simulation models to support natural resource managers with planning and management across a range of space and time scales.

Globally, two broad policy responses to address climate change have been identified. The first is mitigation, which is aimed at slowing down climate change by moderating greenhouse gas emissions. The second is adaptation, which is aimed at adjusting resource uses and economic activities to moderate potential impacts or to benefit from opportunities associated with climate change. The focus of this workshop is on the latter approach. Specifically, we will explore the use of a risk-based approach to developing climate change adaptation strategies in the forest management sector.

### *Climate Change, Forests, and their Management*

Climate change effects are expected to occur faster and be more pronounced over the middle and high latitudes of the Northern Hemisphere continents. With more than 400 million hectares of forested land, including a significant portion of the world's boreal forests, there is keen Canadian interest on the effects of climate change on forests and their management. Recent research into the potential effects of climate change on Canadian forests has raised awareness of the need to address climate change in forest management practices (Standing Senate Committee on Agriculture and Forestry 2003, Climate Change Impacts and Adaptation Directorate 2002). The traditional research focus on the biophysical effects of climate change has, in recent years, been expanded to address socio-economic effects.

### *Biophysical Effects*

The biophysical effects on Canadian forests are expected to be numerous. Effects may be either negative or positive, and they will interact in complex ways over many spatial and temporal scales depending on physical geography, forest type, forest management practices, etc.. Table 1 provides a sample list of some of the potential biophysical effects that may be experienced on a local or regional basis.

**Table 1.** Potential Biophysical Effects of Climate Change on Canadian Forests

| Potential Negative Effects | Potential Positive Effects |
|---|---|
| • Increased frequency and severity of fire due to a longer fire season, drier conditions, and more lightning storms | • Enhanced plant productivity stimulated by increased levels of carbon dioxide for photosynthesis |
| • Expanded ranges and increased winter survival for insects causing increased defoliation and tree kill | • Replacement of slower growing forest tree species with faster growing, higher rotation ones |
| • More extreme weather events such as ice storms, heavy winds, and severe drought | • Faster tree growth resulting from a longer growing season/longer frost-free periods |
| • Reduced snow cover causing more frost heaving and exposure of roots to thaw-freeze events | • Forest migration into previously treeless landscapes, and increased afforestation opportunities |
| • Individual species niches lost to moisture stress or competition from exotic species | • Increased plant hardiness in some species |

***Socio-economic Effects***

Biophysical effects will have numerous corresponding and interrelated socio-economic effects. Throughout Canadian forests, many communities rely heavily on the forest sector market economy. Significant changes in timber supply, whether through increased forest disturbance or decreased forest productivity, will have wide ranging effects on the profitability of local industries and employment levels in communities. Effects will also extend to the provincial and federal level, where revenues from taxes and resource rents provide the basis of program and service provision. Forests also provide numerous non-market benefits to Canadians by providing aesthetic, cultural, and heritage value. Parks and protected areas, which provide valued recreation opportunities and serve important conservation and heritage aims, may face particular challenges if the maintenance of existing natural species and ecosystems is not possible in a fixed location. Perhaps most overlooked are the potential effects on the ecosystem services provided by Canada's forests, including air and water purification, wildlife habitat, medicinal plants, nutrient cycling, and erosion control to name a few.

As the need to adapt to the effects of climate change becomes more apparent, there is a growing demand for incorporation of the full range of both market and non-market values into forest planning and management activities.

### ***Risk-based Approach to Climate Change Adaptation***

Adaptation to climate change refers to adjustments in ecological, social, and economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change (Smit and Pilifosova 2001).

In some circumstances, it may be most appropriate to allow adaptations to occur autonomously, in a natural and unmanaged way. For example, long-term unmanaged shifts in species composition in a timber supply area (i.e., ecological system change) might be followed by autonomous adaptations in the private sector to use the new type of forest resource (i.e., economic systems change). In other circumstances, it may be most appropriate to undertake adaptations in a planned, proactive manner. For example, long-term shifts in forest disturbance patterns that threaten ecological, social, or economic systems might necessitate planned adaptations in the form of targeted regeneration, silviculture, or protection strategies. This section introduces a framework for approaching this latter form of planned adaptation.

Early management approaches to climate change emphasized impact assessment methodologies where climate change scenarios were identified, biophysical and socio-economic impacts were estimated, and management strategies were developed. More recently, vulnerability assessment methodologies have been promoted where key system vulnerabilities are first identified, and adaptive strategies are developed and evaluated in the context of existing decision processes (Smit and Pilifosova 2002, UNEP/IES 1998, Spittlehouse and Stewart 2003). Integrated with the vulnerability focus is the notion of assessing the adaptive capacity of an affected biophysical or socio-economic system to cope with the potential impacts of climate change.

The purpose of this workshop is to demonstrate the practical application of vulnerability assessment concepts in the development and evaluation of climate change adaptation strategies in the forest management sector. Drawing upon recent research that advocates the use of risk analysis and structured decision-making methods (UKCIP 2003, Turner *et al*. 2003), we structure the approach into a generic, flexible planning framework (Figure 2). Our focus, as described below, will be on the planning and decision-making steps, recognizing that effective implementation and monitoring using an adaptive management cycle is also an integral part of a broad risk-based approach to climate change adaptation.

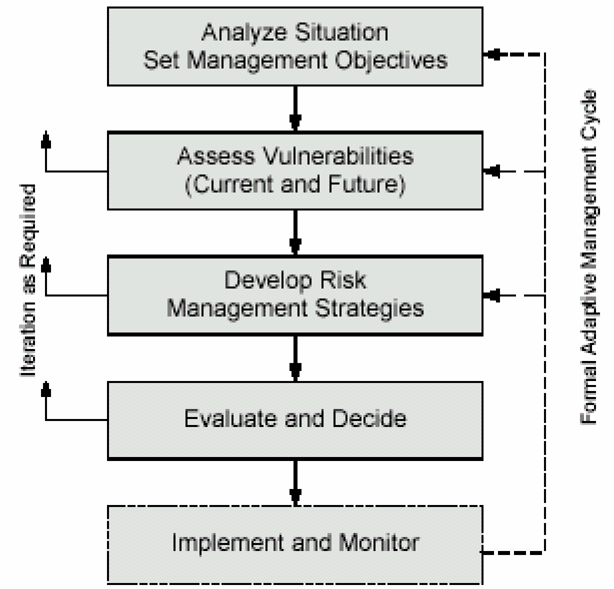


**Figure 2: Risk-Based Approach to Climate Change Adaptation**

***Step 1—Analyze Situation and Set Management Objectives***

Formulating and specifying the forest management context is a critical step. Rarely will forest management planning and decision-making processes be undertaken that are driven solely by climate change issues. More often, climate change will be only one of several important factors to be addressed by a plan or decision.

As a first task, forest managers should undertake a situation analysis to succinctly summarize all key biophysical/ecological, socio-economic, policy, and institutional considerations. Specific information to incorporate into a situation analysis is listed in Table 2 (next page).

Once the forest planning or decision-making context is defined, management objectives should be clearly articulated. Management objectives define the things that matter, the resources or management endpoints that decision makers and stakeholders care about and that may be vulnerable to climate change.

**Table 2.** Considerations to Address in a Situation Analysis

| |
|---|
| **Key Biophysical / Ecological Considerations**<br>• Define the planning and management area<br>• Identify key issues, differentiating between short and long term<br>• Identify key uncertainties (climate or otherwise) and information gaps |
| **Key Socio-Economic Considerations**<br>• Define the linkages with local / regional economic activity and social values<br>• Identify key issues, differentiating between short and long term<br>• Identify key uncertainties (climate or otherwise) and information gaps |
| **Key Policy and Institutional Considerations**<br>• Define the existing policy / regulatory framework and constraints<br>• Define the time horizon for the plan / decision<br>• Identify the institutions, jurisdictions and stakeholders involved and their<br>• authority / mandates<br>• Identify available resources (e.g., staff, budget, data, models, etc). |

A good set of management objectives should be:

- Complete: Addressing everything that matters.
- Concise: Manageable in number so as not to overly complicate the process.
- Measurable: Using either quantitative or qualitative performance measures.
- Controllable: Within the context and authority of the process.

Management objectives can often be derived from existing plans or guiding policy statements. They should be stated by clearly identifying both the object of importance and the direction of preference, e.g., *maximize* timber supply, *protect or enhance* recreation, *minimize* implementation costs. In most forest management contexts, objectives can be organized into environmental, social, and economic categories. Clearly stated management objectives form the basis on which all risk management strategies are later evaluated.

For each management objective, a corresponding performance measure is required to serve as the basis for describing the absolute or relative performance of alternative risk management strategies in measurable terms. For example, for the general management objective to "maximize timber supply," the performance measure might be "the average annual timber volume available for harvest." This measure meets several important criteria: it is predictive (using basic timber supply modelling techniques), accurate (directly relating to the stated objective), understandable (to all stakeholders) and practical (developed using readily available information and resources). While usually developed in quantitative terms, in some circumstances it might be appropriate or necessary to develop performance measures qualitatively, using constructed scales.

In a risk management context, such as when addressing the future effects of climate change, performance measures should also be designed to report the nature, extent, and significance of uncertainty and variability. For example, the average annual timber volume discussed above could be represented as a probability distribution. This information can be critical to expose if, for instance, alternative management strategies have similar expected outcomes (e.g., average harvest volume) but differ widely in the probability of extreme outcomes (e.g., harvest volume falling below levels that would trigger mill shutdown).

***Step 2—Assess Vulnerabilities***

The extent to which ecosystems or socio-economic systems are vulnerable depends on both exposure to climate change (or other) effects and on the adaptive capacity of the system. In order to conduct a vulnerability assessment, the first task is to trace the exposure pathways that lead from climate to our previously stated management objectives. Influence diagrams (Figure 3), also called conceptual models or impact hypothesis diagrams, link stressors (such as climate change or other system influences) to management objectives (such as timber supply or recreation). They can be used to identify important exposure pathways, communicate system vulnerabilities, and target information collection efforts.

From a planning perspective, it may be beneficial to first assess vulnerabilities under the base case or "current" climate before attempting to address alternative future climate scenarios. The experience and knowledge of managers, experts, and stakeholders can often be relied on to quickly document the most important system vulnerabilities. For example, it may be determined that certain management objectives are sensitive to variations in key climate-driven effects such as drought frequency or annual frost-free days. Consideration of past weather variability and extremes may provide useful insight into potential vulnerabilities under different future climate change scenarios.

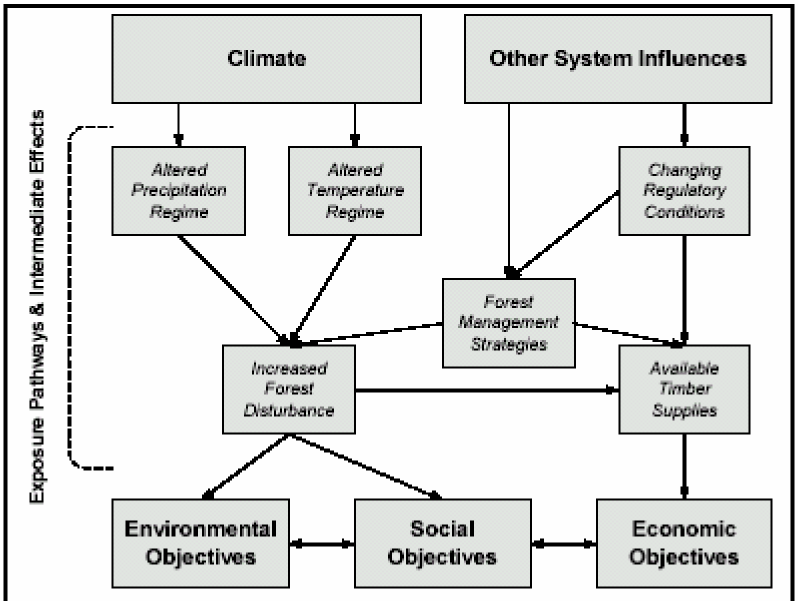


**Figure 3: Conceptual Model Relating Climate and Management Objectives**

General information on future climate scenarios is often readily available from established sources (e.g., the Canadian Climate Impacts Scenarios Project, or the Intergovernmental Panel on Climate Change). Depending on the planning circumstances and available resources, regional-specific future climate scenarios can be developed in a number of different ways. It may be possible to use additional bio-climate modelling to downscale global climate change scenario predictions into useful regional-scale predictions. Alternatively, experts can be consulted or simple "what if" gaming can be used to develop future climate scenarios.

The overall intent of the vulnerability assessment step is to document key exposure pathways and to identify which management objectives are sensitive to change under both current and future climate scenarios.

***Step 3—Develop Risk Management Strategies***

While some adaptive responses to climate change will be autonomous (i.e., those that occur naturally without public sector intervention), others will need to be planned and proactive. Step 3 involves developing a sound risk management strategy as a collection of planned, proactive actions using a structured approach.

The first task in developing a risk management strategy is to brainstorm and categorize a list of all possible management actions. In most cases, there will be a range of specific options that are possible for any given management objective identified in Step 1, or any given vulnerability identified in Step 2. For instance, using the example of managing a timber supply area, different options will be available for fire protection (e.g., increase suppression capability, develop fire-smart landscapes), forest regeneration (e.g., planting drought-tolerant genotypes, controlling invasive species), and silviculture treatment (e.g., managing tree densities and species composition, altering rotation age). During the development of an overall risk management strategy, emphasis should be placed on identifying no regret actions, that is, those management actions that perform well under current climate or any future climate scenario.

From a complete and categorized list of all possible management actions, we can then begin to develop a range of broader management strategies made up of different combinations of management actions from each category. Figure 4 shows how a strategy table can be used to assemble alternative management strategies from a set of categorized lists of management actions. In the conceptual example, strategy "A" is comprised of forest protection actions 1.1 and 1.2, regeneration actions 2.1 and 2.2, and silviculture action 3.1, etc. Alternative strategies can be developed to address specific climate change scenarios (e.g., major increase in drought frequency or decreases in annual frost-free days) or to represent different management goals (e.g., to target a more diverse tree species mix, or alternative size class distribution).

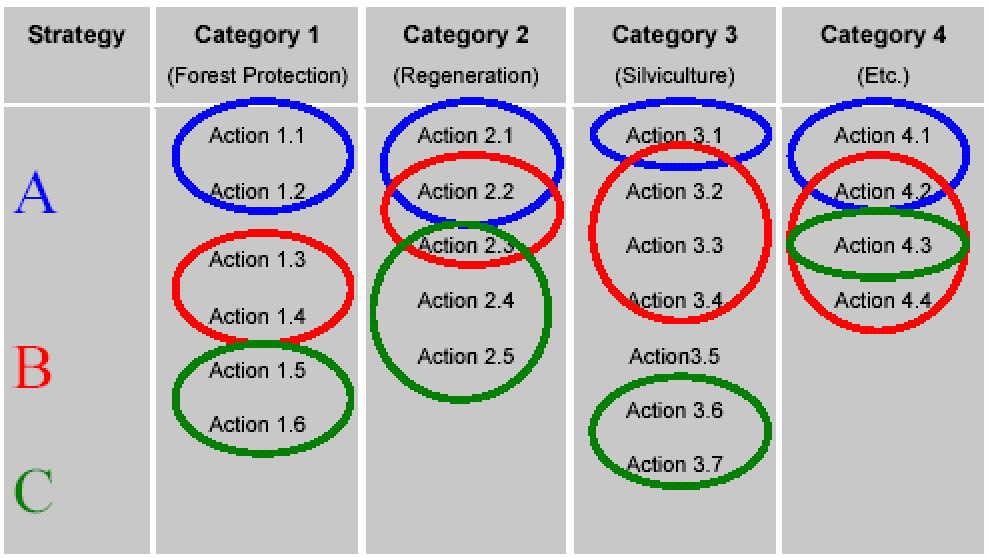


**Figure 4.** Use of a strategy table to guide development of management strategies.

The goal in Step 3 is to systematically develop alternative, internally consistent forest risk management strategies that will address long-term vulnerabilities to climate change or take advantage of opportunities.

### *Step 4—Evaluate and Decide*

Once alternative risk management strategies are defined, they must be evaluated in terms of their effects on the stated management objectives. A simple format for structuring the evaluation is shown in the consequence table of Figure 5, where the cells of the matrix are filled in with the expected consequences of each strategy on each management objective using the performance measures.

The value of the consequence table format is that it efficiently summarizes the trade-offs that may exist either across strategies or across objectives. Selection of the "best" strategy is based on the values and risk tolerances of the given decision maker, which can vary across stakeholders and across circumstances. There are a variety of tools and techniques in guidebook style documents that describe in detail the various tools and techniques to support the evaluation of management strategies (UNEP/IES 1998, UKCIP 2003). These include cost-benefit analysis and multi-criteria analysis, e.g. scoring and weighting.

Therefore, it is important to distinguish between the technical task of describing consequences, and the values-based task of evaluating consequences and trade-offs. In most planning and management processes and contexts this process is an iterative one during which multiple strategy refinements are made until an optimal balance of all consequences is found.

The description of consequences during the evaluation and decision step should include an explicit and understandable expression of underlying uncertainties. For example, one strategy may have a higher expected area of old-growth forest, but also a high probability of catastrophic disturbance, whereas another strategy may have a lower area of old-growth forest, but also a lower probability of catastrophic disturbance. These types of trade-offs should be exposed to decision makers. The goal is to identify and select those management actions and strategies that are robust in the face of uncertainties presented by alternative future climate scenarios.

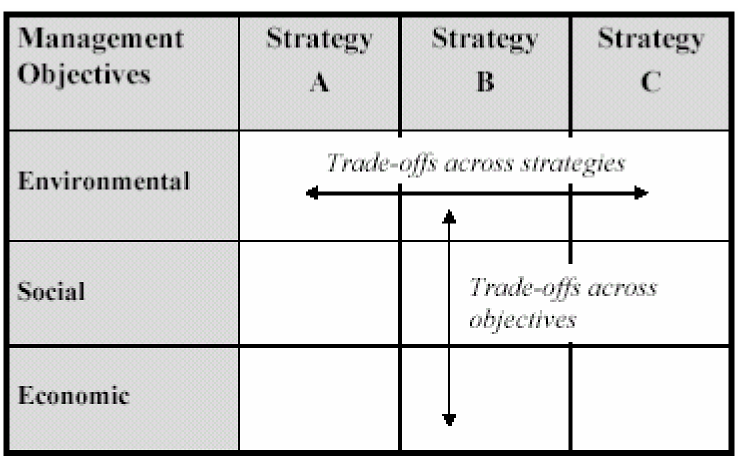


**Figure 5.** Consequence table for evaluation of risk management strategies.

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## Appendix Two: Case Study for a Managed Forest under Climate Change—Tembec's Tree Farm License #14

*This case study provided background information for participants in the breakout groups, held on the second afternoon of the workshop.*

*The Columbia Mountains Institute of Applied Ecology would like to thank Kari Stuart-Smith and her colleagues at Tembec Forest Industries of Cranbrook, British Columbia for preparing the first draft of this document. It was later amended by Greg McKinnon, C-CIARN Forest Sector, for the purposes of this workshop.*

### *Description of Area*

Tree Farm Licence (TFL) 14 is a remote forested area in the mountains of southeastern British Columbia. Most of TFL 14 lies within the Eastern Purcell Mountains Ecosection of the Columbia Mountains and Highlands Ecoregion. The benchlands bordering the Columbia River in the eastern part of the TFL lie within the East Kootenay Trench Ecosection of the Southern Rocky Mountain Trench Ecoregion. The TFL 14 area comprises the major drainages of the Spillimacheen River, Bobbie Burns Creek, Vowell Creek, and their tributaries. Rugged mountains with rocky peaks and alpine areas, glaciers, very steep slopes, and avalanche chutes surround the license area.

The diversity of topography, climate, and soils is reflected in the forest vegetation found within the TFL. Five biogeoclimatic zones are represented: Interior Cedar-Hemlock (ICHmk1) and ICHmw1 variants), Interior Douglas-fir (IDFdm2), Engelmann Spruce–Subalpine Fir (ESSFdk and ESSFwm), Montane Spruce (MSdk), and Alpine Tundra (AT). The predominant commercial tree species are: lodgepole pine (46%), Engelmann spruce (16%), subalpine fir (balsam, 14%) and interior Douglas-fir (13%). There are small amounts of aspen, paper birch, and cottonwood.

TFL 14 is bordered by three protected areas: Glacier National Park (established 1886) borders the western side of the TFL; the Columbia Wetlands Wildlife Management Area (established 1996) borders the eastern side of TFL; and the Bugaboo Alpine Recreation Area (established 1969 and expanded in 1994) occupies a 24,600 ha area on the south side of TFL 14, near the headwaters of Vowell, Conrad, and Crystalline Creeks. Two National Parks— Kootenay and Yoho National Parks—are close to the TFL to the east.

There are no communities within the TFL. A small rural community of approximately 500 people, Parson, is located on Highway 95 which runs along the Columbia River and wetlands on the eastern side of the TFL. The nearest larger communities are Golden (30 km north along Highway 95) and Invermere (about 80 km south along Highway 95). The small communities of Harrogate, Spillimacheen, Brisco, Edgewater, and Radium are within 50 km, also south of Parson along Highway 95. Forestry, mining, ranching, and tourism operations form the main basis for year-round employment and economic activity for these communities.

### *Climate*

The climate of TFL 14 is generally wetter and milder than the Rocky Mountains due to the geographic influence of the Purcell Ranges. There is little climate data for TFL 14, although nearby Golden has over 100 years of climate data. Generally, snow is gone at lower elevation by mid-April, and lingers at higher elevations until late June/early July.

Average temperatures increased over most of British Columbia during the 20th century. Winter and spring are warmer on average than they were 100 years ago. The average winter temperature at Golden for 1961–1990 was –7.8°C and the average spring temperature was 5.8°C. The 94-year record shows an increase of 2.1°C per century in winter and 1.5°C per century in summer, both of which are statistically significant (95% confidence level). Higher temperatures drive other changes in climate systems and affect physical and biological systems in British Columbia.

***Biophysical and Ecological Considerations***

TFL 14 is located in an area of complex and rugged topography. The diversity of elevation, climate, and soils support a broad variety of ecosystems and habitat types, which support many wildlife species including large mammals such as elk, mule deer, white-tail deer, moose, black and grizzly bear, and mountain goat, as well as numerous small mammals. Approximately 150 species of birds are known to use the TFL area.

Forty-seven vertebrate species are considered closely associated with forest structural conditions that occur or could occur on the TFL. At present, five blue-listed species are known to occur or potentially occur: Great Blue Heron, Flammulated Owl, northern long-eared myotis, grizzly bear, and wolverine. Two of these (Flammulated Owl and northern long-eared myotis) are closely associated with forest structural conditions and habitat elements currently blue listed by the BC Conservation Data Centre. The Western Grebe is the only red-listed species known to occur on the TFL.

Streams in most of TFL 14 are glacial in origin and characterized by cold water temperatures, high turbidity during the period of upslope snowmelt (June–August), seasonally fluctuating water levels, and relatively low biological productivity. Only Driftwood Creek and the small tributaries of the Columbia River along the eastern slope are non-glacial in origin and these waters are generally warmer, less turbid, and more productive. Fish are generally confined to the main stem of the streams and rivers, although eastern brook trout and rainbow trout are found in the tributaries of the Columbia River. Other fish species found in the TFL include westslope cutthroat trout, bull trout, mountain whitefish, pygmy whitefish, sculpins, and suckers.

### ***Socio-economic Considerations***

General

The primary activity on TFL 14 is industrial forestry and there is no significant harvest of non-timber forest products in the licence area.

There are several mineral tenures on the TFL that are either actively involved in mining and/or exploration or are in the process of reclamation. As well, BC Hydro operates a small-scale (4 megawatt) run-of-the-river hydro-electric generation facility on the lower Spillimacheen River.

There are a number of tenured recreational businesses in operation including two heli-skiing/heli-hiking operators and a backcountry skiing and hiking operator, each with lodges either in operation or under development. A guide-outfitter runs hunting trips throughout the TFL, operating out of a number of small backcountry cabins, and a snowmobile tour operator offers several different winter excursions. TFL 14 is also used by the public for hiking, hunting, fishing, camping, snowmobiling, and skiing. There are 10 Forest Service Recreation sites located on the larger lakes, most of which are stocked with game fish and receive fairly regular public use.. The Invermere Hut Society operates two public backcountry huts for skiing and hiking in remote sub-alpine regions of the TFL.

Private land borders much of the east side of the TFL area with a few properties located within the boundaries. Private land ranges from small rural residential properties to large family farms. Several domestic watersheds have active water licences serving private properties with water intakes located within the TFL boundaries. There are several domestic water users who own private land adjacent to, and within the TFL, and who rely on water from within the TFL for drinking and domestic use. A number of active traplines are operated throughout the TFL as well as two grazing (livestock) licences.

For years, forestry, mining, and ranching operations formed the main basis for year-round employment and economic activity for people who live in numerous small communities along the Highway 95 corridor adjacent to TFL 14. In recent years, tourism has become increasingly important through commercial backcountry recreation operations, small lodges, and bed and breakfast establishments. Like many other small rural communities in British Columbia that are dependent on timber, mining, and ranching , the communities adjacent to TFL 14 have experienced a significant downturn in economic activity in recent years. The root causes of the changes are complex, related to changes in technology and world commodity market prices, corporate restructuring, and cost-reduction measures. Recently, this downturn in rural communities has been accompanied by a reduction in government services and closures of government offices. Thus, many local residents are concerned about the future of their small businesses and communities, and in the maintenance of basic infrastructure. The recent changes to Tembec Forest Industries' Parson operation and the 2002 closure of the elementary school in Parson have focused these concerns.

*Industrial forestry*
Tree Farm Licence 14 is a long-term forest tenure issued by the Government of British Columbia to Tembec Forest Industries Inc. (Tembec) for forest management purposes. The tenure allows Tembec to harvest, process, sell, and distribute wood products derived from the forest area.

The actual scaled volume of logs cut from TFL 14 over the last five years (1998–2002) is 855,000 $m^3$ or an average of 170,900 $m^3$ per year.

Tembec uses a combination of even and uneven-aged management systems, including clearcuts, clearcuts with reserves (including variable retention cuts), shelterwoods, group selection and occasionally single tree selections systems to harvest stands on TFL 14 that average 325 $m^3$/ha. Approximately 60–65% of the forest cover is comprised of stands with a high component of lodgepole pine, which is either mature or approaching maturity. Typically, 30–60% of the annual harvest is made up of either proactive harvesting in highly susceptible pine stands (usually selective harvesting of larger cutblocks) or salvage logging to address current beetle infestations and recently killed timber. Salvage harvesting usually involves numerous small harvest units ranging from a single load to blocks of several hectares. With increasing beetle populations in recent years, harvesting to address mountain pine beetle has involved up to 80% of the annual harvest on the TFL.

A combination of harvesting methods is used on the TFL. About 70% of the logging is conventional ground-based harvesting systems involving feller bunchers with articulated grapple skidders or small crawlers. Eight percent of the harvesting is “unconventional,” using helicopters and long line logging. The remaining 22% is high lead and skyline cable yarding. About 40% of the falling is done by hand fallers where mechanized harvesters are restricted by terrain, access, or sensitive soils.

Approximately 45% of the forested land base that contributes to timber production on TFL 14 is comprised of stands 60–100 years old, and 16% are greater than 140 years old. The TFL occupies 150,431 hectares; 74,388 hectares (49%) are covered in productive forest.

Forest management on the TFL generates approximately 100 person-years of direct employment and local people are employed in almost all of the staff positions and contracted work on the TFL.

***Policy/Regulatory Framework***

In British Columbia the *Forest and Range Practices Act* (*FRPA*) and its regulations define the legal requirements for planning and practices on provincial crown land, community forest agreements, and most woodlots. The *FRPA* planning framework contains the requirement for two plans: 1) the Forest Stewardship Plan (FSP), which contains results and strategies consistent with government objectives and identifies harvesting and road activityand is submitted to government for approval, and 2) a Site Plan that holders of a FSP must prepare. Site plans describe how the results and strategies in approved FSPs apply to the site.

Science-based effectiveness evaluations and professional reliance are considered cornerstones of the *FRPA* framework.

***Management Objectives for TFL 14***

Land use management in the Rocky Mountain Trench, as well as in TFL 14 specifically, is generally very complex because of the large number of very high, and sometimes competing, resource values. In 1995, a long process to develop a Kootenay Boundary Land Use Plan was completed for the whole east and west Kootenay region and was implemented in 2000. It established land use zones, including an extension to a protected area, and established targets for management.

TFL was recently awarded Forest Stewardship Council certification, on the basis of a successful audit in October 2004. Management of the TFL is consistent with the principles and criteria of sustainable forest management as identified by the Forest Stewardship Council in ecological, social, and economic arenas.

***Impacts of Climate Change***

General

Projected climate change for the area encompassing TFL 14 is for a mean annual temperature increase of 1.9°C to 3.7°C by the mid-21st century (range based on 10th–90th percentile of SRES projections). Precipitation is expected to increase by 7 mm per decade in spring (from current 116 mm), 5 mm per decade in winter (from current 253 mm), and annually 30 mm per decade (from current 765 mm).

The amount of precipitation that falls as snow will continue to vary from year to year in response to natural climate cycles. Climate models project, however, that as the Earth's atmosphere continues to warm, the extent of snow cover in the Northern Hemisphere will continue to decrease during the 21st century. The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that in mountainous regions of North America, particularly at mid-elevations, higher temperatures could lead to a long-term reduction in peak snow-water equivalent, with the snowpack building later in the year and melting sooner.

Furthermore, the IPCC has concluded that in regions where seasonal snowmelt is an important aspect of the annual hydrologic regime—such as the basins of the Fraser, Columbia, and Peace rivers warmer temperatures are likely to result in a seasonal shift in runoff, with a larger proportion of total runoff occurring in winter, together with possible reductions in summer flows. Some snowmelt-dominated river basins could shift towards a mixed snow-and-rain regime, with increased runoff during the winter months. River temperatures will continue to vary from one year to the next in response to short-term natural climate variability. As the climate warms, however, years with warmer river temperatures are expected to occur more frequently. In addition, river temperatures may more often exceed those levels that are optimal for fish.

Productivity and markets

Future climate change may increase the productivity of northern forests, at least in the near term. However nutrient availability and acclimation by trees are likely to limit the longer term potential for increased growth. As well, markets and trade in forest products play important roles in whether a region realizes any gains associated with climate change. In general, regions of the world with the lowest wood fibre production cost will be able to expand harvests.

*Natural disturbance*

It is generally considered that climate change could induce rapid changes in forest age class distribution and landscape patterns through altered timing and increases in the frequency and intensity of disturbances, such as fire, wind, ice storms, and pests.ith respect to the latter, TFL 14 is currently vulnerable to mountain pine beetle, and this vulnerability can be expected to increase with climate change.

Future climate change may increase the thermal and moisture stress on the existing forest. Stressed and aging tree populations will be more vulnerable to insects and disease and the regeneration phases of forest succession will be particularly susceptible to a changing climate. Because the potential for wildfire often increases in stands after insect attack, uncertainties in future insect damage patterns magnify uncertainties in fire regimes.

Root diseases and decay affect vast areas over time in terms of plant growth, species composition, and stand structure. Although not generally viewed as landscape-level processes or disturbances, their impact on the landscape may be more influential than larger scale agents such as fire and primary insects.. Results of harvesting and stand-tending practices in second-growth stands are creating conditions for increased incidence and loss from root diseases. Climate change can be expected to create abnormal stress conditions in forest stands. Tree stress is one of the major factors affecting the incidence and spread of root disease infection. The combination of climate change stresses, compounded by the interference of forest management practices, will have major negative impacts on biomass production in conifer forests.

*Forest operations*

Biological and climate changes have implications for forest operations. Increased winter precipitation could affect water management in forests. An increased risk of sediment transport to streams could degrade water quality and fish spawning habitat. Warmer winters will reduce the opportunities for winter logging in areas where the frozen surfaces of forest roads and ice bridges are essential for site access and where a snowpack is necessary to protect the land during harvesting.

*Wildlife habitat, biodiversity, and protected areas*

Climate change will affect habitat quality and availability for wildlife and species ranges are expected to shift upward in elevation and northward in latitude in the Northern Hemisphere.

Climate change is recognized as a key threat to biodiversity. For example, a spatially explicit example of projected tree migration for Ontario, coupled with global climate model projections, suggests that climate change could result in considerable species loss, especially if migration fails to keep pace with the warming. The effects of climate change on biodiversity in the local area comprising TFL 14 are unknown but can be expected to be adverse, given intrinsic low migrational capabilities of many species and local physical barriers to migration.

There is increasing pressure on forest managers to incorporate biodiversity and recreational use into their long-term planning. The steady-state protected area system adopted by most federal and provincial-territorial jurisdictions to help maintain biodiversity, was developed with assumptions of climatic and biogeographic stability; assumptions that an accumulating body of research indicates are no longer valid. Landscape and stand level protected area strategies, wildfire management strategies, non-native species management programs, and species re-introduction programs would also appear to be vulnerable to the impacts of climate change.

*Stream flow, water quality, and aquatic habitats*
The presence of even a small amount of glacier cover in a catchment can influence stream flow variability on a range of time scales and glaciers advance and retreat in response to changes in local climate. During the 20th century most glaciers in southern British Columbia retreated and this retreat is expected to continue and accelerate during the 21st century.

Glacial melt feeds many mountain streams and rivers in British Columbia. In glacier-fed rivers, the highest flows tend to occur in early or mid-summer, depending on latitude, and glacier runoff can account for significant portion of the available water supply.

Glacier retreat is therefore likely to cause changes in the flow patterns, and possibly the temperature, of some streams and rivers. These changes—along with other climate driven changes to hydrological systems—will likely have significant impacts on freshwater and estuarine ecosystems and on aquatic species. They will affect other biological systems and human activities that depend on water. In the short term, melting glaciers will likely discharge more water into some British Columbia streams and rivers. This may provide short-term benefits for hydroelectric generation, water-based recreation, fisheries, and other water users. Higher flows may also, however, increase stream turbidity and damage fish habitat and riparian areas. In the longer term, glacier retreat will likely mean reduced water volume in glacier-fed streams and rivers, especially during the summer months. In water-short regions, this could generate increased competition between various water users.

*Social impacts*
Changes in resource availability will have a large impact on communities where lifestyle is strongly tied to these resources for food and culture. In particular, TFL 14 lies within the traditional territory of the Shuswap and the Columbia Lake First Nations Bands and these First Nations, who have a large stake in the long-term condition of the forest, may be particularly vulnerable.

## Appendix Three: Case Study for a Protected Area under Climate Change—Mount Revelstoke National Park

*This case study provided background information for participants in the breakout groups, held on the second afternoon of the workshop.*

*The Columbia Mountains Institute of Applied Ecology would like to thank Susan Hall and Michael Morris of Parks Canada for preparing the first drafts of this document. It was later amended by Jenny Fraser of the B.C. Ministry of Water, Land and Air Protection and Greg McKinnon, C-CIARN Forest Sector, for the purposes of this workshop. Note that some artificial elements were added to the scenario.*

### *Description of Area*

Mount Revelstoke National Park (MRNP) is located in southeastern British Columbia north of Revelstoke. It is bordered on its southern edge by the Trans Canada Highway and the Canadian Pacific Railway; on its western edge by Highway 23 North and Lake Revelstoke; and on the northern and eastern sides by provincial managed forests. The City of Revelstoke borders the southeastern corner of the park. MRNP is 250 $km^2$ in size and includes the Selkirk Range, known for its steep, rugged slopes and heavy snowfalls.

### *Management Objectives*

Like all national parks, MRNP has the primary mandate to maintain ecological integrity while providing opportunities for human use and enjoyment that are compatible with this goal. The *National Park Act* and supporting polices, as well as other applicable federal legislation (such as the *Species at Risk Act*), require federal park managers to maintain biodiversity; protect the habitat of species at risk; recover or re-introduce endangered and extirpated species (where feasible); and interfere as little as possible with natural processes (e.g., fire, disease, and insects), unless such interference can be justified by threats to other resources. The MRNP management plan calls for identifying and protecting old and ancient forests, while allowing natural fires to occur in other areas where resources such as park facilities, nearby settlement, and provincial forests are not threatened.

### *Climate*

The climate station closest to the park is in Revelstoke. Between 1961 and 1990 average spring temperature at Revelstoke was 7.1°C and average winter temperature was -3.8°C. During the 20th century, average temperatures increased over most of British Columbia, particularly during winter and spring. The 101-year record at Revelstoke shows increases of 1.3°C per century in spring and 1.2°C per century in winter. (The spring temperature trend is statistically significant at the .05 level.)

Precipitation information is available for the Southern Interior Mountain Ecoprovince in which Revelstoke is located. Between 1961 and 1990 average annual precipitation was 765 mm. Average precipitation by season was: spring, 116 mm; summer, 183 mm; fall, 213 mm; and winter, 253 mm. During the 20th century average precipitation increased, particularly in spring and summer. The 70-year record across the ecoprovince shows precipitation increases of 30 mm per decade annually, 7 mm per decade in spring, and 6 mm per decade in summer. (All trends are statistically significant at the .05 level.)

### *Hydrology*

Melt waters from the Clachnacudainn Icefield in Mount Revelstoke National Park make their way to the Illecillewaet and Columbia rivers. Preliminary analysis suggests that many glaciers are retreating rapidly and could disappear over the next century. Glaciers provide much of the base flows of streams during the late summer low flow period. Most of MRNP lies within the Wet Climate Region of the interior, characterized by warm, wet summers and cool winters with deep snow. The late-lying snowpack prevents soils on most sites from drying out until late summer. These characteristics have, in the past, contributed to low fire frequency. A recent analysis of climate data confirmed a strong trend to lower- and short-duration snowpacks at valley bottoms and reduced snowpack throughout.

### *Biogeoclimatic Zones*

Slightly more than half of the park is above the treeline in the Alpine Tundra zone, and consists of rock (38% of the total land base), ice (11%) and alpine meadow (3%). Slightly less than half of the park is below the treeline, and consists of two forested biogeoclimatic zones:

- The Interior Cedar Hemlock zone (ICH), at 500–1200 m elevation, occupies 14% of the land base. Subzones include two wet and cool variants: ICH vk1 (Mica Very Wet Cool) in the upper tributaries, and ICH wk1 (Wells Gray Wet Cool) in the lower tributaries and along the Illecillewaet River. They also include a warmer, drier variant -- ICH mw3 (Thompson Moist Warm) on the south facing slopes of Mount Revelstoke.
- The Engelmann Spruce–Subalpine Fir Zone (ESSF) at 1200–2200 m elevation, occupies 19% of the park area. The predominant subzone is a wet climate variant -- ESSF vc (very wet cold).

Avalanche chutes are laced vertically throughout the landscape and occupy 14% of the MRNP land base.

### *Flora*

MRNP harbours a very high diversity of plant and lichen species. Rare plant species are found predominantly in lowland ancient forests, bluff grasslands along south-facing slopes, wetlands, avalanche chutes, subalpine meadows and seeps, and subalpine cirques.

The park contains rare old (i.e., 200–400 year old) and very rare ancient (i.e., 400 years plus) forest stands. Associated with old and ancient cedar-hemlock forests are lichen communities and two provincially rare ferns. Many lichen species associated with old and ancient MRNP forests are associated with unique micro-habitats such as very large fallen logs, nutrient-enriched sites (for example, enriched toe slopes and run-out zones of avalanche paths) and the splash zones of waterfalls. Rare lichen species in riparian and wetter forests may be subject to loss via climate warming and associated drought stress.

Alpine meadow plant communities also support a very high plant biodiversity in MRNP, including many provincially—and one nationally—rare plants. High elevation plant communities may become "at risk," as they are expected to shrink due to rising treeline and forest in-growth as climate warms and the growing season lengthens.

Avalanche chutes and run-out zones support high biodiversity. Green-up occurs early in the chutes, which are snow free early in the season. Chutes are very important as early season food sources for grizzly bears and provide habitat for songbirds that prefer a shrubby, moist, non-forested habitat. The low gradient run-out zones have riparian characteristics due to the accumulation of snow (which provides moisture later into the summer) and the accumulation of organic material brought down by avalanches. A reduced snowpack in a warming climate could alter the character of MRNP's species-rich, avalanche-path communities.

Wetlands are uncommon in the park, and of high value where they occur. The impact of glacier retreat, combined with a reduced snowpack and earlier spring, could be significant for wetlands and other riparian habitats throughout MRNP.

### *Fauna*

Northern sections of MRNP and adjacent provincial forest lands are habitat for a small group of mountain caribou, a red-listed species whose population has been declining since the beginning of the 20$^{th}$ century. MRNP does not appear to be core habitat, due its small land base and steep, avalanche-prone terrain. Despite the protection provided by MRNP and the habitat guidelines on adjacent provincial land, the local herd fragment declined from an estimated 121 individuals in 1994 to 38 in 2004. Caribou require contiguous mature and old forest on moderate terrain—forests that support the high biomass of lichens that caribou depend upon for food. Caribou are intolerant of fragmentation by early seral forests. Within the park, drier sites with high value mountain caribou attributes (e.g., high lichen biomass and understorey forage species such as false box) may be more vulnerable to fire and insect epidemics as a consequence of climate change.

Other species at risk found within MRNP include the great blue heron, northern long-eared myotis, grizzly bear, wolverine, bull trout, western toad, and the Coeur D'Alene salamander. The latter has highly specialized habitat requirements (rocky seeps and waterfalls) and a very localized distribution. Northern alligator lizards live on the drier, south-facing, low elevation rocky bluffs of Mount Revelstoke, and although not at risk, are in the northernmost extension of their range in British Columbia. Alpine habitats in the park are critical for marmot and pica, species not currently at risk, and are important for grizzly bear.

### *Disturbances*

Although most forests within MRNP are wet climate subzone variants also found north of the park, the southern portion of the park is transitional between the wet and moist (i.e., drier) climatic regions. The Trans Canada Highway marks the border between the Forest Practices Code Biodiversity Guidebook Natural Disturbance Type 1 (very infrequent fire) and Natural Disturbance Type 2 (infrequent fire). The location of MRNP on the edge of a climatic boundary suggests that climate warming could have a major impact on MRNP's old-growth character and its capacity to support old-growth dependent species.

Fire seasons and fire losses have increased over the last two decades in the Columbia Forest District bordering MRNP. There has been a trend towards lower snowpack at valley bottom weather stations with an earlier onset of spring. This, combined with more frequent summer drought also associated with climate change, suggests a likelihood of greater fire frequency and severity in ICH forests, particularly in warmer and drier subzone variants (i.e., ICH wm3).

During the late 19th century, MRNP lost a significant amount of old-growth forest to fire. Natural losses were likely supplemented by human-caused fires along the railway corridor, located in the drier ICH mw3 subzone. As a result, MRNP includes significant amounts of 80 to 100 year-old stands, compared to predominantly older (i.e., 200 to 400 year-old) forests on provincial land north of the park and distant from the railway. Stand succession and development under a different climate may not follow the same pathways resulting in communities that could be unique and could differ in their capacity to support current old-growth biodiversity, which may be a relic of a past wetter and cooler climate.

Hemlock looper infestations appear to be increasing in frequency and severity within MRNP. Many cedar-hemlock stands along the Trans Canada Highway south of and in MRNP were severely defoliated as a result of the 1990 and 2000 infestations. Depending on the extent of recovery, these stands may not retain their old-growth structure and composition. There is evidence that in the drier ICH variants, forests damaged by hemlock looper may be more susceptible to fire.

Invasive non-native plant species have infested disturbed sites along the borders (e.g., the Trans Canada Highway corridor) and within the park (e.g., lower Summit Parkway, picnic areas, campgrounds, and trailheads). Such infestations are more severe in the drier portions of the park. Non-native plants may invade riparian zones where sites are naturally disturbed as a result of flooding. They have invaded the rare grassland bluff community on the lower slopes of MRNP. Control programs and monitoring are in place, but ongoing disturbance through right-of-way management (e.g., snow removal, ditch grubbing), combined with seed dispersal by motor vehicles, has created a long-term, intractable problem that will likely worsen with climate change.

### *Human Use*

MRNP provides opportunities for high-quality visitor experiences through a mix of facilities intended to support use by visitors of all ages and physical capability. There is a summer-only road (Summit Parkway) leading to the summit of Mount Revelstoke National Park. The rest of the park is accessed by hiking trails. High-use visitor sites along the Trans Canada are located at features such as old-growth forests (Giant Cedars Nature Trail) and wetlands (Skunk Cabbage Nature Trail) and supported by interpretive displays and associated costly infrastructure such as boardwalks. The summit of Mount Revelstoke is famous for its sub-alpine meadow flower displays, and receives more than 80,000 visitors in the short summer, snow-free period of about three months. Due to high visitation, the fragility of these high-elevation plant communities, and past severe damage from unmanaged visitor use, the area is now carefully managed through a network of hardened trails and personal delivery of environmental education aimed at all visitors.

Climate warming could affect the nature and quality of visitor experience and learning opportunities provided by MRNP. Changes in natural conditions—in particular fire, pest infestations, and blowdown—could damage infrastructure at visitor sites and degrade visitor experience. For example, changes in hydrology (e.g., reduction in flows and drought stress) could affect visitor experiences at the

Skunk Cabbage wetland. Risks to the alpine include the likelihood of forest succession (meadow in-fill) and complete loss of these communities and their high aesthetic value. In the interim, drought stress may leave meadow plants more likely to succumb to visitor impacts (e.g., trampling), decreasing biodiversity and the quality of visitor experiences. Expected increases in Parkway closures during periods of high fire risk will also affect visitors and park revenues.

MRNP is not a high profile destination for backcountry skiers. Under climate change, MRNP's ski season will be shortened, but due to very deep snow, even a major reduction in snowpack may not be significant. Avalanche experts predict that less snow will result in more frequent deep slab instabilities that will increase the hazard to winter backcountry users.

### *Climate Change and Adaptation*

Projected climate changes by the mid-21st century include a mean annual temperature increase of 1.9°C to 3.7°C; and a mean annual precipitation change of -163 mm to 948 mm. The 20-year return period level of precipitation is projected to occur more often, with a return period of 8 to13 years (in North America as a whole).

Federal polices do not offer direction regarding protection of endangered species habitat that may be threatened by changes in natural processes associated with climate change. Management of old-growth ecosystems and their unique biodiversity in a period of climate change is expected to present major challenges over the next century. One of the major challenges for the future management of protected areas is that under a changing climate, the maintenance of existing, natural species and ecosystems may not be possible. If, for example, the projected future climate of the park becomes much warmer, especially in spring, natural regeneration of the native forest might become impossible. In such a situation, one of the questions that could be asked is: What types of human intervention (if any) would be appropriate to maintain areas of forest cover within protected areas under climate change?

In the discussion, it may be helpful to examine the three management models presented by Henderson *et al*. (2002) as follows:

**"As-if Wilderness" Management Model**
Treat climate change as a natural process (if historic forests disappear because of increased warming, then so be it).

- Inexpensive in terms of management
- Risk of losing biodiversity
- Risk of losing valued landscapes
- Public concerns if current and historic values lost

**"Frozen Landscape" Management Model**
Management objectives are to maintain or recreate the natural landscapes of the past.

- Easily understood concept
- Success is measurable (historic records)
- These landscapes really did exist, but even natural systems are dynamic
- May be impossible under climate change

**“Managed Retreat” Management Model**

This model accepts landscape change as inevitable.

- Management objective includes the maintenance of forest cover under a changing climate
- Strategy may include active management option, for example: control of fire and pests; enhancing regeneration of existing species; “human-assisted migration” of regionally native species
- Expensive, increasingly intrusive, some options may be controversial
- May help to maximize biodiversity under climate change

## Appendix Four: Application of the Vulnerability Approach to Case Studies

The breakout groups were provided with a set of templates to guide their discussion of how the two case study areas could use the vulnerability approach to adapt to a changing climate. The templates provided at the workshop proved somewhat confusing. They have been reworked, and are included in this document as a resource for participants to use in the future.

### *General Guidance to Workshop Participants*

**Step 1: Define the Problem**

Climate-related risks and opportunities should be examined in the broader context of a resource management decision. Step 1 involves identifying important biophysical/ecological, socio-economic, and policy and institutional considerations. The following templates outline in more detail the information requirements. Much of the required information can be found in the case study. Group members should be able to provide other relevant information.

**Step 2: Identify Management Objectives**

**Management Objectives:**
- Identify an object and a preferred direction of change.
- Focus on ends (outcomes) rather than means.
- Categorize objectives into environmental, social, and economic themes.

**Performance Measures:**
- For each objective, identify one or more measures of performance that would enable you to assess whether or not the objective has been met.
- Performance measures selected should be predictive, measurable, understandable, and practical.

**Information Sources (examples):**
- Identify sources of information relevant to measuring performance, for example relevant documents, interviewees, databases, field work, and models.

**Step 3: Assess Vulnerability**

In carrying out this step, start from management objectives. Consider various relevant time scales (e.g. present, 20 years from now, two rotations from now etc.). Consider extreme events (e.g. extreme climate and climate-related events, market extremes).
- Identify management objectives that are sensitive to climate change and/or its impact.
- Identify specific assessment endpoints and exposure pathways.
- Assess the adaptive capacity of the ecosystem in question (i.e. protected area, managed forest) and/or the management system.

The most **vulnerable** outcomes are those where sensitivity is high and existing adaptive capacity is low.

This initial assessment (for the purpose of this exercise) is a ‘Screening Assessment” that is qualitative, and based on expert judgments and local knowledge. Under other conditions, such an assessment would be the first of three Tiered Assessments, with the other two tiers being:

- Generic Assessment: semi-quantitative
- Detailed Assessment: fully quantitative.

**Step 4: Identify Risk Management Options**

Brainstorm and categorize individual actions:

- Brainstorm ways to meet each management objective.
- Identify from Step 3 the areas of greatest vulnerability. Identify management options to address these vulnerabilities. Try to identify *no regrets* options that convey benefits now as well as in the future

**Step 5: Develop Alternative Risk Management Strategies**

Assemble alternative strategies as logical, internally consistent sets of actions

- Start with a ‘status quo’ strategy that assumes current management approaches
- Develop alternatives by budget level: “do a little” vs. “do a lot” and by theme: “diversification”, “transition with natural systems”, or “active intervention”.

**Step 6: Assess Trade-offs and Identify the Most Effective Strategy**

The process of selecting an appropriate management strategy involves making comparisons between different, internally consistent strategies, and making trade-offs across strategies and across management objectives. The following diagram illustrates this process. Identify some of the trade-offs that might need to made in managing a TFL or protected area in the face of climate change? Which management strategy would be most effective?

***Evaluating and Deciding: Making Trade-offs***

| **Management Objectives** | **Strategy A** | **Strategy B** | **Strategy C** |
|---|---|---|---|
| Environmental | | *Trade-offs across* | |
| Social | | *Trade-offs across* | |
| Economic | | | |

*TEMPLATES ARE ON THE FOLLOWING PAGES.*

## MOUNT REVELSTOKE NATIONAL PARK
### Step 1: Define the Problem

| CATEGORY | IMPORTANT CONSIDERATIONS |
|---|---|
| **Ecological/biophysical**<br>1. Define the planning and management area<br>2. Identify key indicators & describe their current status & future trends<br>3. Identify issues – differentiate between short term vs. long term<br>4. Identify risks & uncertainties | |
| **Socio-economic**<br>1. Describe the key linkages with local economic activity and social values<br>2. Identify key indicators & describe their current status & future trends<br>3. Identify issues – differentiate between short term vs. long term<br>4. Identify risks & uncertainties | |
| **Policy and Institutional**<br>1. Define the existing policy/regulatory framework (policies, regulations, standards)<br>2. Identify the institutions / jurisdictions involved:<br>a. Authority & mandates<br>b. Roles and responsibilities<br>c. Specific initiatives (including goals)<br>d. Decision making mechanisms (including consultation requirements)<br>3. Describe availability of resources (staff, budget, information, models, etc. | |

## MOUNT REVELSTOKE NATIONAL PARK

**Step 2: Identify Management Objectives** *[Examples provided]*

| | MANAGEMENT OBJECTIVES | PERFORMANCE MEASURES | INFORMATION SOURCES |
|---|---|---|---|
| **ECOLOGICAL** | • *regional representation of flora and fauna*<br>• | • *age class distribution*<br>• *species composition*<br>• | • *use of indicators, monitoring*<br>• |
| **ECONOMIC** | • *generate income to contribute to operating costs of national parks*<br>• | • *cost of park management*<br>• | • *records of income and expenditures*<br>• |
| **SOCIAL** | • *provide opportunity to present and future generations to experience natural ecosystems*<br>• | • *visitor satisfaction*<br>• | • *surveys*<br>• |

## MOUNT REVELSTOKE NATIONAL PARK

### Step 3: Assess Vulnerability *[examples provided]*

| | MANAGEMENT OBJECTIVES | SENSITIVITIES TO CLIMATE | |
|---|---|---|---|
| | | CURRENT | FUTURE |
| **ECOLOGICAL** | • *Maintain biodiversity representation*<br>• | • | • |
| **ECONOMIC** | • *generate income for operating national parks*<br>• | • *visitor numbers & revenues go down when weather is wet and cold* | • |
| **SOCIAL** | • *provide present and future opportunities to experience nature*<br>• | • | • *glaciers will shrink or disappear as a result of warming* |

## MOUNT REVELSTOKE NATIONAL PARK

## Step 4: Identify Management Options *[examples provided]*

| | Management objectives | Vulnerability (related to climate) | Management Option 1 | Management Option 2 | Management Option 3 |
|---|---|---|---|---|---|
| **Ecological** | *Maintain biodiversity representation* | | | | |
| **Economic** | *Generate income for operating national parks* | *Potential reduction in visitor numbers* | *Increase capacity for year-round activity and visitor use.* | *Increase commercial operations in park* | |
| **Social** | *Provide present and future opportunities to experience nature* | *Potential loss of glaciers* | *Identify and highlight other important natural features for visitors* | *Include glacier retreat in park interpretative program.* | |

## MOUNT REVELSTOKE NATIONAL PARK
## Step 5: Develop Risk Management Strategies *[examples provided]*
## Step 6: Assess Trade-offs and Identify the Most Effective Strategy

| | Management Objectives | Strategic Response A | Strategic Response B | Strategic Response C |
|---|---|---|---|---|
| **Ecological** | *Maintain biodiversity representation* | *?* | *?* | *?* |
| **Economic** | *Generate income for operating national parks* | *Increase capacity for year-round activity and visitor use.* | *?* | *Increase commercial operations in park* |
| **Social** | *Provide present and future opportunities to experience nature* | *?* | *Include glacier retreat in park interpretative program.* | *Identify and highlight other important natural features for visitors* |

## TREE FARM LICENCE 14
## Step 1: Define the Problem

| CATEGORY | IMPORTANT CONSIDERATIONS |
|---|---|
| **Ecological/biophysical**<br>5. Define the planning and management area<br>6. Identify key indicators & describe their current status & future trends<br>7. Identify issues – differentiate between short term vs. long term<br>8. Identify risks & uncertainties | |
| **Socio-economic**<br>5. Describe the key linkages with local economic activity and social values<br>6. Identify key indicators & describe their current status & future trends<br>7. Identify issues – differentiate between short term vs. long term<br>8. Identify risks & uncertainties | |
| **Policy and Institutional**<br>4. Define the existing policy/regulatory framework (policies, regulations, standards)<br>5. Identify the institutions / jurisdictions involved:<br>a. Authority & mandates<br>b. Roles and responsibilities<br>c. Specific initiatives (including goals)<br>d. Decision making mechanisms (including consultation requirements)<br>6. Describe availability of resources (staff, budget, information, models, etc. | |

## TREE FARM LICENCE 14
## Step 2: Identify Management Objectives *[Examples provided]*

| | MANAGEMENT OBJECTIVES | PERFORMANCE MEASURES | INFORMATION SOURCES |
|---|---|---|---|
| **ECOLOGICAL** | • *Maintain ecosystem health* | • *Local level criteria and indicators (examples?)*<br>• | • *use of indicators, monitoring*<br>• |
| **ECONOMIC** | • *maintain current level of revenue from forestry* | • *volume of wood harvested*<br>• | • *?*<br>• |
| **SOCIAL** | • *maintain or enhance number of families supported by TFL*<br>• | • *?*<br>• | • *?*<br>• |

## TREE FARM LICENCE 14
## Step 3: Assess Vulnerability

| | MANAGEMENT OBJECTIVES | SENSITIVITIES TO CLIMATE | |
|---|---|---|---|
| | | CURRENT | FUTURE |
| **ECOLOGICAL** | • *Maintain ecosystem health* | • | • |
| **ECONOMIC** | • *maintain current level of revenue from forestry* | • | • |
| **SOCIAL** | • *maintain or enhance number of families supported by TFL*<br>• | • | • |

## TREE FARM LICENCE 14
## Step 4: Identify Management Options

| | Management objectives | Vulnerability (related to climate) | Management Option 1 | Management Option 2 | Management Option 3 |
|---|---|---|---|---|---|
| **Ecological** | • *Maintain ecosystem health* | | | | |
| **Economic** | • *maintain current level of revenue from forestry* | | | | |
| **Social** | • *maintain or enhance number of families supported by TFL*<br>• | | | | |

## TREE FARM LICENCE 14
## Step 5: Develop Risk Management Strategies
## Step 6: Assess Trade-offs and Identify the Most Effective Strategy

| | Management Objectives | Strategic Response A | Strategic Response B | Strategic Response C |
|---|---|---|---|---|
| **Ecological** | • *Maintain ecosystem health* | | | |
| **Economic** | • *maintain current level of revenue from forestry* | | | |
| **Social** | • *maintain or enhance number of families supported by TFL*<br>• | | | |

## Appendix Five: Notes from Breakout Groups

*On the second afternoon of the workshop, participants broke into groups to test the concepts presented at the workshop. These pages record the summary of each group's findings, as presented at the plenary session late in the afternoon.*

### ***Protected Area Group One***

*Facilitator: Bill Taylor*

*Purpose of the Park (Objectives)*

Maintain ecological integrity
- Processes, species, identify indicators for monitoring
- As per *Species at Risk Act*, *National Park Act*

Provide recreation, year round
- Winter is cross-country skiing, ski-touring
- Summer is hiking, driving to summit, viewing wildflowers and scenery, cycling, guided trips such as school groups.

Set Ecological benchmarks
- Monitor ecosystem changes
- Serve as natural laboratory

Protect species
- Species at risk, e.g., mountain caribou, Couer d'Alene salamander
- Habitat whole or partial

Enjoyment
- Tourism as a benefit to Canadians
- Natural setting (beauty) is part of enjoyment
- Peace of mind, knowing that park is there
- May need facilities to enable this

Protect water sources

Protectfrom human development and activities

Education
- Interpretation
- School groups

Economic activity
- Park is a tourist draw, nearby town benefits

Glaciers
- Viewing
- Possible protection (side discussion!)

*Vulnerabilities*

Recognize importance of habitat diversity
- Maintain rather than increase diversity
- Assume current state is the natural state

Vulnerability to fire
- Vulnerable to what is around the park, and also what happens in the park affects what happens outside of park

Establish priorities for fire
- Have performance measures, plans in place

Insects
- Forest defoliators, current hemlock looper outbreak,
- What will be effects on understorey and implications, e.g., bear food

Caribou as an endangered species
- Snowpack changes will affect lichen growth
- Rainfall/snowfall variability may affect ability to move on snow

Enjoyment /Recreation
- Increased fire hazard may mean closures
- Campfire bans and use bans due to risk
- Reduced access
- Winter—reduced season if less snowpack
- Summer—longer season, more chance for impact on trailside, changed demographic of visitors (age, time of use, length of stay)

Bears
- Change in food supply may mean increased bear/human interaction in park, nearby community, and outlying residents

Source of Water
- Impacts on hydrological regime due to increase variability in snowmelt /rainfall
- Watershed could be vulnerable to changes, e.g., fire in park

Loss of riparian areas and wetlands and associated species and processes

Wildflowers
- Affected by changing availability of water
- Changed by season of snow
- Invasion of trees into meadows if treeline rises

Endangered Species and ecosystems
- Lichens—ecology of tree canopy will change/move, impact greatest for lower inhabitants of the tree canopy (affects caribou)
- Alpine community vulnerable—no new habitats to move into, nowhere to go.

Park Infrastructure
- Picnic shelters, bridges, outhouses, backcountry cabins, roads, signs
- May be affected by fire, flood, changed snowpack

*Risk-management Strategies*

Reduce other pressures so system can handle changing climate better
- Eliminate invasive noxious species
- Quota system for human use pressures

Educational opportunity/enjoyment
- Show what change has happened
- Explain what actions park is taking

Fire management
- Allow fire to clean out trees encroaching meadows?
- Build relationships with fire agencies external to park

Monitor change
- Currently have weather stations
- Need more monitoring tools

Species at risk
- Triage?
- Trade-offs?
- Short-term measures to keep populations viable?

Balance the objective and actions with feasibility and cost

Maintaining old -growth forests
- Think about replacement of these over time, fire protection in up-and-coming old growth?

## ***Protected Area Group Two***

*Facilitator: Robin Sydneysmith*

| Management Objectives | Vulnerability to Climate Change | Strategies |
|---|---|---|
| **Ecological**<br><br>1. (relatively) undisturbed benchmark of the region (moderate intervention)<br>2. maintain regional representation of flora and fauna including species at risk. | Old and ancient forests<br>Mountain caribou/ habitat<br>Low elevation valley bottom riparian<br>Transportation corridor<br>Pests<br>Fire<br>Tree types: spatial compression of feature biogeoclimatic zones<br>Increase in pests, fire, and drought<br>Loss of icefield<br>Loss of tundra/alpine meadow<br>Loss of SAR: caribou lost to ungulates, deer, and moose | Accept inevitable change, but "managed retreat," porosity, resilience, try to reduce cumulative effects |
| **Economic**<br><br>Maintain visitor opportunity, i.e., role in local economy as tourist destination | Declining visitation: smoke, closures, destroyed areas<br>Invasion of exotics is a huge expense<br>Future visitation decrease<br>Invasive species cost of removal | Diversifying visitor opportunities, for example: adding climate change effects as an educational feature |
| **Social**<br><br>Education, interpretation, experience natural ecosystems. | Loss of appeal due to loss of attractions<br>Avalanche risk increase, threat to recreation? | Diversifying visitor opportunities, for example: adding climate change effects as an educational feature; identifying and reporting on climate change impacts in the park |

## ***Managed Forest Group One***

*Facilitator: Dave Spittlehouse*

***Objectives***

As given in handout.

***Vulnerabilities***

Potential shrinking of forested land base
Potential increase in natural disturbances
Increase in frequency of extreme weather events

- Extremes occurring a critical growth times could cause significant losses

Caribou are extremely vulnerable
Grizzly bears are extremely vulnerable

- Avalanche path habitats may be altered

Global markets need to be considered—timber production affected by climate change elsewhere
Invasive plant species may increase
Water supply—timing, quantity, quality, loss of glacier source

- Need a index to monitor hydrological situation

Ecosystem may become less resilient

***Strategies***

Take plan for lower elevation cutblock and push it upslope

- From timber production perspective, climate change may prove to be a good opportunity—more production higher up

Maintain ecosystem resiliency

- Leave more buffers
- Does dead timber act as buffer also?
- Value may be greater as standing timber than as forest products

Maximize biodiversity and ecosystem integrity

- Need a suite of indicators for “ecosystem health”

Continue pest proofing strategies
Capture topographic sequences
Redefine the representation strategies for protected areas
Timber supply review should consider climate change – recognize this in models.
Diversification
Community economic diversification funded by resource user fees

- Community management of forests—revenues to community to keep cash flowing
- Put stumpage fees up—money goes to communities
- Carbon tax on fossil fuels

Invest in skills, training, and alternative energy sources
New strategies for defining protected areas, e.g., topographic sequences

***Additional Points:***

Soil is a function of vegetation, time, climate, and topography
Snow is a limiting factor for tree growth in the alpine
There is large terrain variability within the Tree Farm Licence
What is the timeline for the Forest Service Plan versus climate change?
Biodiversity indexes are needed to measure performance

## ***Managed Forest Group Two***

*Facilitator: Jenny Fraser*

| **Management Objective** | **Vulnerability** | **Strategy** |
|---|---|---|
| Safety | Forest fires | • Fire Smart practices such as fire breaks and barriers<br>• Escape corridors<br>• Maintain roads for crew access<br>• Convert wood bridges to metal |
| Ecological Integrity | • Competitive relationships<br>• Increased stresses<br>• Change in range | • Limit hunting – decommission roads and use gates<br>• Minimize stress from current management<br>• Maintain connectivity<br>• Limit number of people living in or using the TFL |
| Improving $CO_2$ sinks | Forest survival (pests, disease, drought, fire) | Uneven-age management<br>Planting of diverse species |

***Topics that needed further discussion:***

Water quality
Insects
Tourism (snowpack, snowmobiling)
Soil
Road infrastructure
Worker Safety (landslides, avalanches)
Wildlife

***Lessons learned from process:***

Climate change will affect the TFL on ecological, social, and economic fronts
Some items cross all three fronts
Trade-offs will be necessary (e.g., close roads to keep out hunters vs maintain roads for fire crew access)
Be ready for unexpected—climate change may exacerbate current problems or new may appear
Management objectives need performance measures
The process of climate change is an opportunity to educate
How do you manage for current variability?  Learn from this

## Appendix Six: Highlights from Participants' Evaluation Forms

*Evaluation forms were distributed at the workshop. Twenty-seven forms were returned from the 115 participants. The following is a summary of responses.*

***Question One: How did the workshop meet your expectations?***

- Fourteen people said very well, extremely well, excellent.
- Five people said good, expectations exceeded, expectations met, great, better than I expected
- Two people said fairly well, had no expectations.

Specific comments:

- Generally good—some presentations were not really that applicable to me, e.g., Harding, Benson.
- At times information was overwhelming. Need better discipline for speakers so they can communicate to a broader group interest.

***Question Two: Which aspect of the workshop was most useful to you?***

Most useful:

- Seven people mentioned the workshop was useful for networking and making contacts.
- Several people rated talks as most useful to least useful. The rating was not consistent.

Specific comments:

- Quality and knowledge of speakers was high.
- Liked the application of the climate change information to specifics, e.g. the caribou talk.
- Liked the longer time per speaker than most conferences have.
- Glad there was no talk about "global warming."
- Question-and-answer periods were useful.

Least Useful:

- Five people had comments along the lines that they wanted "more local case studies and real life experiences, less of the theoretical, broader concepts."
- Two people—general presentations on government policy not useful.
- One person—not enough time for questions.
- Comments about breakout groups not being useful are summarized in Question 3.

Specific comments:

- There were contradictory approaches—climate change is a reason to discount and not do anything to protect species at risk, but a reason to do even more to protect commercially harvested tree species that may disappear.
- Technical modelling details were not useful.

- “Flashing” of complex slides not very useful

***Question Three: How effective was the afternoon working group session in increasing your understanding of climate change impacts and adaptation?***

Positive: 14
Negative: 8

Note that about a third to a half of the workshop participants left at noon and did not attend the breakout groups.

Specific comments:

- Several participants indicated they did not learn more about climate change, but they appreciated the chance to try an exercise.
- Helped give an understanding of the complexities involved.
- Good in as far as understanding a process to use.
- I don’t assume information quickly so was not able to be effective in the workshop.
- Although it didn’t work well it was a good idea, could have used more direction from facilitator.
- Needed more time given the complexity of the task, but a good taste.
- Great discussion although we did not focus on the task.
- Having a completed example from the real world would be useful for future workshops. Would like to promote, modify, and apply for own area.
- Handouts could have been more organized.
- Enjoyed the discussion and debate.
- It would have been better to use a fictitious protected area, as the participants were far too wrapped up in the actual location and management constraints and unwilling to “just do the exercise.”

***Question Four: Would you like to see more workshops on climate change in the future?***

- Four people—Water: quality and quantity, changes
- Six people—Specific information on potential impacts, nuts-and-bolts brainstorming to come up with strategies to deal with changes; more specifics, more practical information, at regional level; focus on day-to-day implications for a number of different perspectives (lists sectors); on-the-ground adaptation, restoration, mitigation, and monitoring
- Two people—Climate change and invasive species in southern interior grasslands
- Two people—Species at risk management in the context of climate change
- Social science perspectives on climate change—what do citizens think? What does traditional ecological knowledge tell us?
- Biodiversity changes as a result of climate change
- Identify vulnerabilities of each ecosystem in British Columbia and develop strategies
- Need to look at mitigation (Kyoto) in light of our value system around wild spaces
- Snow, avalanches, and the ski industry
- How to monitor for climate change, what are good performance measures?

- What are the barriers to species migration? Follow through on the idea of new locations for biogeoclimatic zones but how will species get to those locations; what will things look like in mean time, wants a rigorous examination of this

***Question Five: How did you hear about this workshop?***

Friend, co-worker: 3
CMI email: 5
CMI web site: 3
Email: 4
Y2Y list serv: 1
FORREX: 2
BioNews (RPBio of BC): 1
RPF list serv: 1
Invited speaker: 3
From a presenter: 1

***Question Six: Please complete this sentence: As a result of this workshop I plan to….***

- Three people—Follow up with contacts made at workshop.
- Three people—Check out the models and recommended resources available on the web sites.
- Add a section on climate change to a publication I am working on.
- Always include it as a consideration in decision making.
- Attend future CMI workshops.
- Browse web sites that give maps, data, and scenarios.
- Buy a more efficient vehicle.
- Draft a letter to my clients summarizing what I have learned and proposing that we draft management strategies for their properties that anticipate the effects of climate change.
- Find funds to apply Greg's analysis approach to our community forest and our community.
- Follow up on web site recommended by presenters.
- Further develop the range of adaptation options available to my agency.
- Get more in-depth information from the web sites.
- Hire someone to help me address climate change issues.
- Integrate thinking about climate change into my daily thinking and ride my bike to work.
- Promote its consideration among my colleagues in the forest service.
- Promote more discussion and awareness of the adaptation strategies in my community.
- Pursue opportunities for research related to climate change restoration.
- Rethink my views of NDT4 restoration—how will it change given climate change?
- Seek consideration of climate change in timber supply revision and four forest practices.

- Share information and perspectives with work colleagues, and suggest ways we can incorporate some of the lessons learned as we develop British Columbia government policy, and as we consider organizational change after the election.
- Start hoarding water, keep telling friends, and family.
- Talk to Canfor in Prince George about some of the ideas we learned here.
- Think about how to incorporate climate change into local land use planning.
- Try to become involved in invasive species management (large scale) in the context of climate change—e.g., soil amendments to encourage native species growth.
- Work harder to lower my greenhouse gas emissions.

### *Question Seven: Additional Comments*

- Would like to have had a field trip component.
- Venue: would appreciate a venue with windows and daylight, with less transportation issues and fewer GHG emissions.
- Wants to be linked up for car–pooling to get here.
- Wants shorter presentations, more questions.
- Wants more incentives and opportunities for non-experts to enter discussion.
- Great session.
- Two people noted: Great opportunity for youth (reference to Selkirk College and Revelstoke Secondary students that attended).
- Some presenters had overlapping information.
- Two people noted there were no female presenters.
- Good food by United Church women, appreciated vegetarian options.
- Shouldn't hand out single-sided photocopies (note—CMI did not prepare the handouts).
- Good pacing and handling of objectives.
- Wanted CMI to calculate $CO_2$ used by people attending conference and mitigate. Include cost in conference fee.
- Make sure presenters avoid theoretical generalities and focus on specific details.
- Enjoyed the range of backgrounds of presenters and participants.

### *Question Eight: Suggestions for Future CMI Events*

- Evaluate how well the provincial biodiversity strategy is working in this region.
- Include endangered species.
- How do we improve decision-making and governance processes around sustainability goals in the Columbia Mountains?
- Include science-based updates and refreshers.
- Incorporate land conservation (covenants, easements, and acquisition) by land trusts into species at risk and connectivity issues.
- Broader coverage of sciences related to ecology – hydrology, soils, geomorphology
- Include ecological restoration in practice.
- Offer extension workshop for educators on global warming and climate change.

## Appendix Seven: Climate Change Scenarios for Southern British Columbia

Jenny Fraser, Climate Change Policy Analyst
B.C. Ministry of Water, Land and Air Protection, Victoria, British Columbia
December 2004

Jenny Fraser kindly provided the following information, which is extracted from the web sites of:

- Canadian Climate Impacts Scenarios Project (CCIS) and the Canadian Institute for Climate Studies (CICS) web site at www.cics.uvic.ca/.
- Environment Canada web site at: www.ecoinfo.ec.gc.ca/env_ind/region/climate/climate_e.cfm.
- Ministry of Water, Land and Air Protection web site at: http://wlapwww.gov.bc.ca/air/climate/indicat/index.html
- University of Washington's Climate Impacts Group (includes Canadian portion of the Columbia River Basin) at: http://cses.washington.edu/cig/pnwc/cc.shtml

### *1. Where to Find Information for the Columbia Basin*

Visit the **Canadian Climate Impacts Scenarios Project** (CCIS) and the Canadian Institute for Climate Studies (CICS) web site at www.cics.uvic.ca/. The CCIS web site can provide historic information as well as future climate scenarios based on coarse resolution global climate model outputs. Climate parameters included are: mean temperature, precipitation, minimum and maximum temperature, specific humidity, incident solar radiation, wind speed, evaporation, soil moisture, mean sea-level pressure, snow water content, sea ice, derived vapour pressure, derived relative humidity, derived diurnal temperature range, surface temperature, geopotential height.

CCIS presents monthly values for Creston for: temperature, growing degree days, precipitation and evaporation, water surplus and deficient and related climate parameters. CICS provides some assistance in using the CCIS web site.

**Environment Canada** provides historic information for Cranbrook Airport, per decade, relative to 1961–1990:

- Tmax: +0.11;
- Tmin: +0.34;
- Frost free days: +4.1;
- Precipitation: +2.3%

See www.ecoinfo.ec.gc.ca/env_ind/region/climate/climate_e.cfm

**Environment Canada** also provides future scenarios for the Okanagan Basin at www.pyr.ec.gc.ca/EN/Climate/climate_scenarios.shtml. Environment Canada trends are summarized in the following pages.

The **B.C. Ministry of Water, Land and Air Protection** (WLAP) documents historic trends for the Southern Interior Mountains Ecoregion:

- Tmax: +0.9
- Tmin: +1.3
- seasonal and seasonal max and min
- precipitation: +4% per decade
- seasonal precipitation; snow depth (no trend); SWE (+4%/decade)
- growing degree days (+13%/century)

See http://wlapwww.gov.bc.ca/air/climate/indicat/index.html.

WLAP also documents historic trends for the Southern Interior ecoregion. WLAP information is summarized in the following pages.

The **Climate Impacts Group (CIG) at the University of Washington** provides historic trend and future scenarios information for the Columbia Basin, and documents related impacts. For historic trends, see http://cses.washington.edu/cig/pnwc/cc.shtml. For future scenarios, see http://cses.washington.edu/cig/fpt/ccscenarios.shtml. CIG information is summarized in the following pages.

## *2. Historic Trends in the Columbia Basin*

### *2a) B.C. Ministry of Water, Land and Air Protection*

Historic data suggest that many parts of British Columbia are already starting to experience some of the impacts of climate change. During the 20$^{th}$ century:

- average annual temperature warmed by 0.6$^{o}$C at the coast, 1.1$^{o}$C in the interior, and 1.7$^{o}$C in the north (between 1895 and 1995)
- minimum temperatures increased by 0.9$^{o}$C at the coast, 1.3 to 1.7$^{o}$C in the interior, and 2.1$^{o}$C in northern British Columbia (between 1895 and 1995)
- growing degree days (GDD), a measure of the heat energy available for plant and insect growth, increased by 5 to 13% (between 1895 and 1995)
- precipitation increased in southern British Columbia by 2 to 4% per decade (between 1929 and 1998)
- sea surface temperature (SST) increased by 0.9 to 1.8$^{o}$C (between 1914 and 2001)
- snow depth and snow water content decreased in some parts of British Columbia (between 1935 and 2000)
- lakes and rivers throughout British Columbia became free of ice earlier in the spring (between 1945 and 1993)

British Columbia trends based on records of 50 to 60 years or longer are more strongly associated with climate change.

*2b) Environment Canada*

This information is extracted from an Environment Canada web site: www.ecoinfo.ec.gc.ca/env_ind/region/climate/Climate%20station . Data sets supporting the figures, and more information, are available at this web site.

The world's climate has not been constant. We know it has gone through dramatic past changes, but there is increasing evidence that human activities are altering our climate at an unprecedented rate. When assessing climate change, natural variability must also be considered. Conditions can vary from one year to the next, and cyclic phenomena like El Niño and the Pacific Decadal Oscillation exert important influences over the climate in the region.

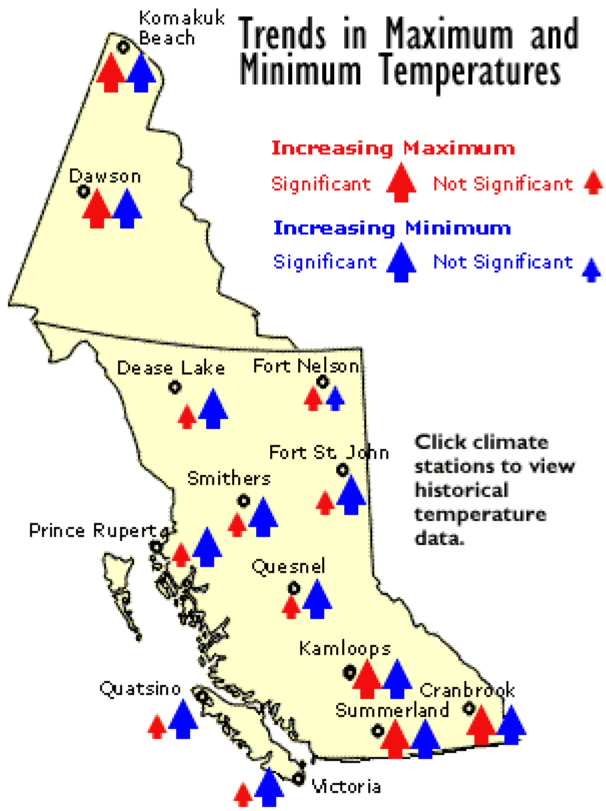


**Figure 1.** Trends in Maximum and Minimum Temperatures in British Columbia and Yukon. Source: Environment Canada, 2001. For more information on climate stations and climatic regions, see www.ecoinfo.ec.gc.ca/env_ind/region/climate/dataset

In spite of these natural climate variations, analysis of temperature data from 13 climate stations across the region shows a general warming trend throughout British Columbia and Yukon. Much of this warming has been measured in the daily minimum temperatures rather than in the warmest part of the day. In other words, temperatures at night have been getting less cold. As can be seen from the map, maximum and minimum temperatures in the region are showing an increasing trend at the 13 climate stations shown. For minimum temperatures, this increasing trend is statistically significant at all stations except Fort Nelson. For maximum temperatures this increasing trend is only significant in the Yukon and in southeast British Columbia (Kamloops, Summerland, and Cranbrook).

As the climate warms, there are fewer days with subzero temperatures and more days with temperatures favourable to plant growth and development. This warming trend is consistent with published data that shows the length of the growing season at a number of British Columbia locations has become measurably longer between 1955 and 1995. The beginning of the growing season appears to be starting about three weeks earlier in the period 19861995 compared to 1946–1955.

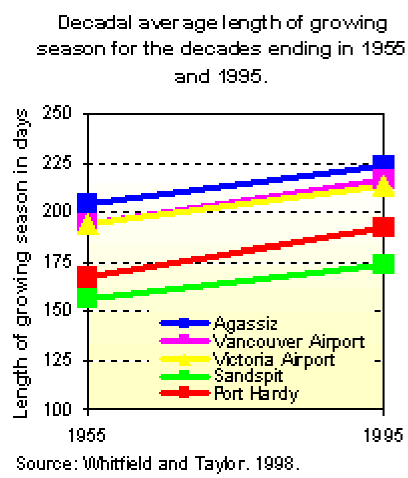


**Figure 2.** Decadal average growing season for the decades ending in 1955 and 1995. Source, Environment Canada 2001.
www.ecoinfo.ec.gc.ca/env_ind/region/climate/Climate%20station

Recent studies by scientists (Taylor and Taylor1997) indicate that the warming trends caused by climate change could have a dramatic effect in British Columbia and the Yukon. Northern Yukon is predicted to experience a shorter but more intense snow season with faster snow melt and longer and warmer summers. The climate change impacts on Yukon ungulates such as the porcupine caribou are expected to be significant as snow depth affects their ability to forage. In areas like the Fraser Valley of British Columbia, warmer temperatures and a decrease in summer precipitation will be factors in the production of ozone and smog. Model predictions suggest summers will become hotter and drier with increasing smog episodes, worsening respiratory impacts, and generally increasing health risks from deteriorating air quality (Thomson 1997).

There could be significant negative effects on water resources of the dry interior of the province, which rely heavily on snow melt, particularly in the mid- to late summer low flow period. Migrating salmon would also be affected if water temperatures become too warm. According to the Pacific Fisheries Resource Conservation Council (2000) climate change may be having the biggest single impact on the deterioration of salmon production, and it poses the most apparent long-term risk to the future of Pacific salmon. Some ski areas in the Rockies and southern British Columbia may have shortened ski seasons. Less snow may also upset sensitive ecosystems and threaten species at the most southern edge of their geographic range. Global warming may add to stratospheric ozone depletion (commonly referred to as the ozone hole). Higher carbon dioxide levels can lower Arctic stratosphere temperatures aiding ozone-destroying chemical reactions. This could delay the recovery of the thinned Stratospheric Ozone Layer and allow more harmful ultraviolet radiation to reach the earth's surface.

The warming trend being documented in British Columbia already appears to be having an effect. Earlier breeding of certain seabirds has already been observed (DFO 2001) as they adjust to the advanced timing of peak prey food availability due to increasing ocean temperatures. As a result, prey availability is mismatched with timing of breeding, chick growth is retarded, and survival is reduced (Bertram *et al*. 2001). The growing abundance of Lesser Snow Geese may be linked to recent warmer summers on their arctic nesting grounds. Also, within British Columbia, the evergreen broadleaf arbutus trees found only in micro-climates along the southwest coast are showing signs of die-back believed to be caused by changing weather patterns.

*Continued…*

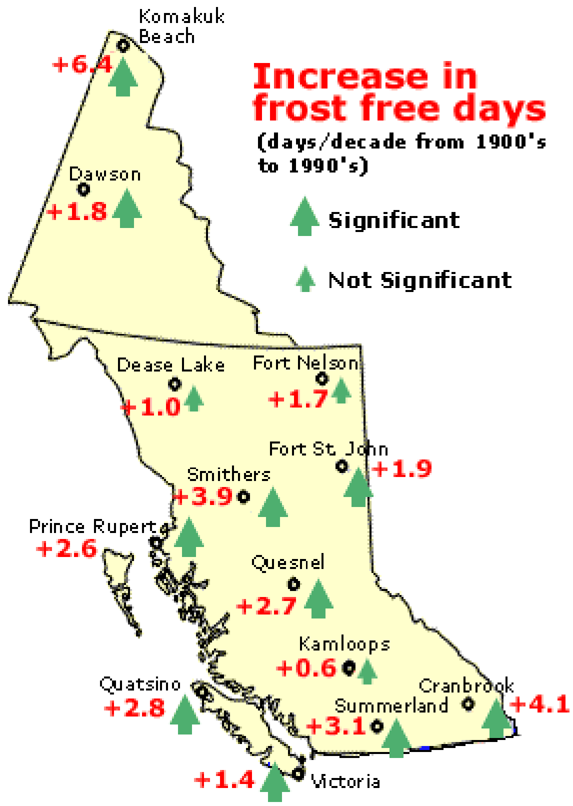


**Figure 3.** Increase in Frost-freeree days in British Columbia and Yukon. Source: Environment Canada, 2001. For the data for each station, view: www.ecoinfo.ec.gc.ca/env_ind/region/climate/Growingseason

Along with the trend in increasing minimum temperatures throughout the region, the numbers of frost-free days have also been increasing across the region. This fits in with data from other regions, like the Canadian Prairies, where there are now 19 more frost-free days a year than 75 years ago. This lengthening of the freeze-free season can improve agricultural growing conditions, but may also increase problems with plant pests and disease. For example, mild winters in north-central British Columbia have contributed to the province's worst forest infestation of mountain pine beetle. Normally controlled by freezing temperatures, the beetle population has been able to increase because of the warmer winters.

Detecting changes in precipitation trends is difficult because precipitation varies widely across even small geographic areas. As can be seen in the map below, although not statistically significant or conclusive, an increasing trend has been measured for annual precipitation throughout most of the region. This increase in precipitation may be explained by increasing rates of evaporation due to warmer temperatures or it may be due to a change in storm frequency.

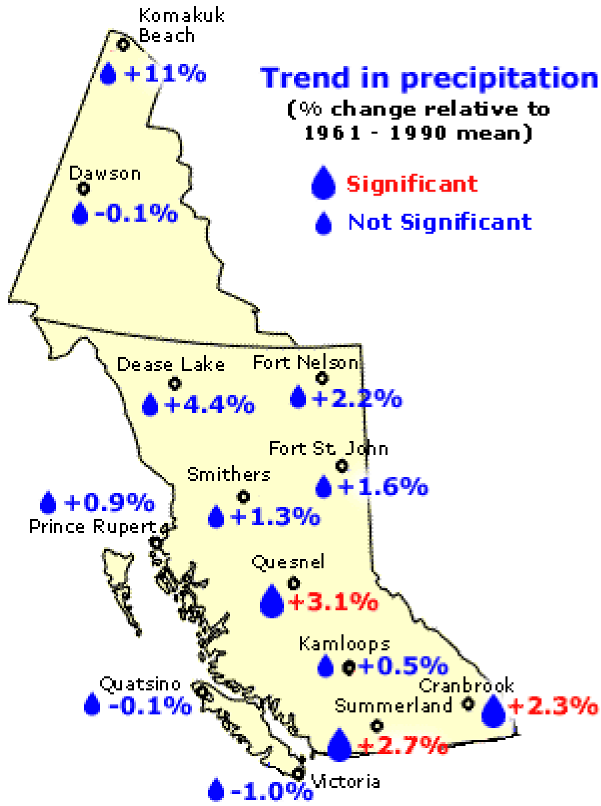


**Figure 4.** Trend in precipitation in British Columbia and Yukon. Source: Environment Canada. 2001. For data for each station, visit: http://www.ecoinfo.ec.gc.ca/env_ind/region/climate/Growingseason

Regional hydrologists have also observed changes in the temporal pattern of stream flows as a result of warmer temperatures. Stream flows in south-central British Columbia peak earlier but have lower early summer fall flows and higher early winter flows (Leith and Whitfield 1998). Similar changes have also been observed in the timing of stream flows of coastal rivers (Whitfield and Taylor 1998) where spring and summer river flows have decreased. These reduced coastal river flows are believed to result from an earlier starting and longer lasting growing season which leads to a lowering of the water table. Such low flow periods will begin even earlier in the year and will last even later into the fall as higher air temperatures increase evaporation from soils and surface waters. Declining stream flows in summer would result in warmer river and lake temperatures and increased fish mortality. Reduced water supplies and increased forest fire hazards would become common in the late summer.

Changes already documented in the Northern Hemisphere during the 20$^{th}$ century include reductions in both snow cover and the duration of lake and river ice cover, a decline in Arctic sea-ice thickness and extent, and a retreat of mountain glaciers. Associated with temperature increases has been an observed increase in global sea levels, at an average rate of 1 to 2 mm per year over the past 100 years. Sea levels at most British Columbia ports are rising by about 1 mm per year and a slight increase in sea level has already been noted in Richmond, British Columbia.

Some researchers have reported that the frequency and intensity of extreme weather events have increased over the last 10–15 years. In the winter of 1998–99 the south coast of British Columbia experienced 15 severe storms instead of the average three. The economic losses from a single blizzard in British Columbia during the 1996–97 winter were about $200 million. Certainly in Canada the number and cost of weather-related disasters have increased as can be seen in the graph above. Although information about extreme weather events continues to be compiled, scientists agree that there is not yet enough scientific evidence to show they are directly linked to a changing climate. The United Nations Environment Program (UNEP2001) has projected that the potential cost of global warming is more than $300 billion.

*2c) Climate Impacts Group, University of Washington*

This group studies the United States' Pacific Northwest including the Canadian portion of the Columbia River. Visit their web site at: www.cses.washington.edu/cig/

The climate of the Pacific Northwest (PNW) has changed during the past 100 years. Observed 20th century changes include:

- Region-wide warming of about 1.5°F (0.8°C) in 100 years. The warming has been fairly uniform and widespread, with little difference between warming rates at urban and rural weather monitoring stations. Only a handful of locations recorded cooling. Although the warmest year was 1934, the warmest decade was the 1990s. Largest increases occurred during winter.
- Increase in precipitation in most of the PNW. Trends in precipitation are more variable than trends in temperature, but most monitoring stations show increases. The largest relative increases were observed in northeast Washington and south- central British Columbia, especially in spring.
- Decline in snowpack—especially at lower elevations—since 1950. Trends in April 1 snowpack have been negative at most monitoring sites in the PNW, and are largest (>50%) at lower elevations where snowpack is more sensitive to temperature. Declines have been largest in the central and southern Cascade Mountains

Spring is arriving earlier in the western United States. Analysis of changes in the timing of peak spring runoff in 279 snowmelt dominated streams in western North America finds that peak spring runoff has advanced 10–30 days earlier into the spring season in 2000 compared to 1948 (Stewart, I.T., D.R. Cayan and M.D. Dettinger, 2004: Changes in snowmelt runoff timing in western North America under a 'business as usual' climate change scenario. Climatic Change 62: 217-232.) The greatest trends occurred in the PNW, including the mountain plateaus of Washington, Oregon, and western Idaho (ibid). These results closely correlate with advances in average bloom-date trends for the purple common lilac (2 days per decade based on data from 1957–1994) and honeysuckle (3.8 days per decade based on data from 1968–1994). Similar results have been found in western Canada, the United States' prairie states, and Europe. (Cayan *et al*. 2001. Changes in the onset of spring in the western United States. Bulletin of the American Meteorological Society 82(3):399-416.)

While it is premature to assume that anthropogenic (i.e., human caused) climate change is driving these trends, the trends are consistent with projected climate change impacts for the PNW.

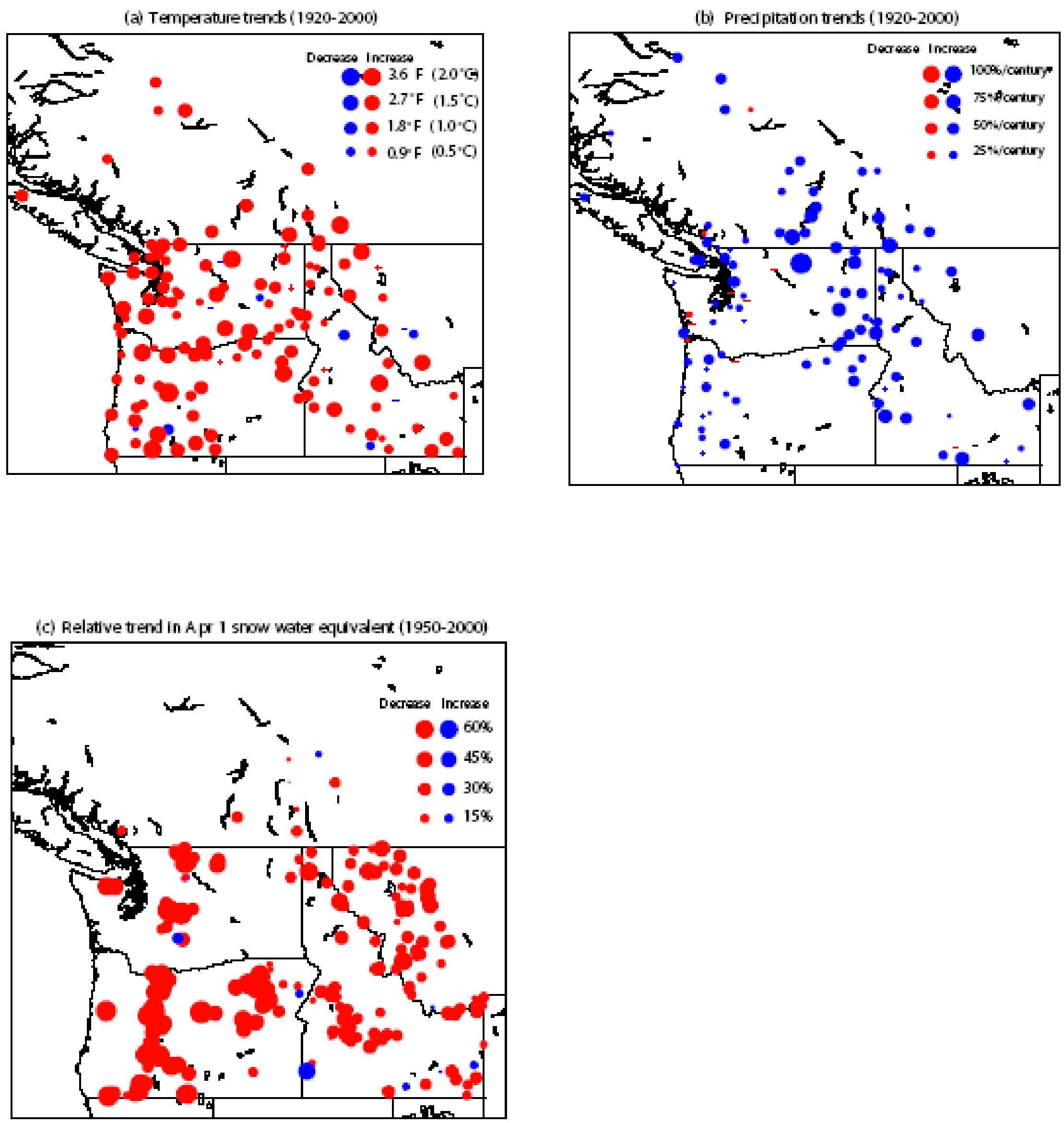


**Figure 5.** Twentieth century trends in (a, b) average annual PNW temperature and precipitation (1920–2000) and (c) April 1 snow water equivalent (1950–2000). These figures show widespread increases in average annual temperature and precipitation for the period 1920 to 2000 and decreases in April 1 snow water equivalent (an important indicator for forecasting summer water supplies) for the period 1950 to 2000. The size of the dot corresponds to the magnitude of the change. Pluses and minuses indicate increases or decreases, respectively, that are less than the given scale.

View larger images of these figures at this web site (scroll down, click on image to enlarge): www.cses.washington.edu/cig/pnwc/cc.shtml#

## 3. Future Climate Projections

*3a) B.C. Ministry of Water, Land and Air Protection*
(Based on Intergovernmental Panel on Climate Change, 2001 and others)

The rate of global warming projected for the 21st century is much faster than observed changes during the 20th century, and likely faster than at any time during the past 10,000 years. The actual rate of warming will depend on how fast greenhouse gases continue to accumulate in the atmosphere, and how the climate system responds. Although climate change appears to be gradual at the global scale, atmospheric warming may in future trigger abrupt changes in regional climate. For this reason, past trends do not necessarily predict how biophysical systems will respond in future.

Climate model scenarios project that during the 21st century British Columbia can expect the following:

- Average annual temperatures to increase by 2º to 7ºC warming by 2100 for most of British Columbia.
- Northern British Columbia continuing to warm faster than other parts of the province.
- Minimum daily temperatures continuing to warm faster than maximum daily temperatures.
- Up to a 20% increase in precipitation by 2100.
- More winter precipitation.
- A greater proportion of winter precipitation falling as rain.

These scenarios and climate change studies project, in addition, the following changes in bio-physical systems for British Columbia:

- Reduced snowpack in southern British Columbia and at mid-elevations.
- An earlier spring freshet on many snow-dominated river systems.
- Reduced summer stream flows, particularly on snow-dominated river systems.
- Glacial retreat and disappearance in southern British Columbia.
- Warmer temperatures in some lakes and rivers.
- Reduced summer soil moisture in some regions.
- Increase in growing degree days.
- Increases in frequency and severity of disturbances e.g. fire, pest outbreaks.
- General movement of species northwards and upslope.
- Changes in habitat quality and availability.
- Large-scale biome shifts.
- Changes in synchrony between species e.g. timing of predator/prey emergence.
- Loss of some types of ecosystems e.g. wetlands, alpine.

The past trends and future projections described above reflect change in average climate. In addition, climate change may also include changes in:

- climate variability, for example the frequency and/or amplitude of the cyclical swings between cool, wet La Niña years, and warm, dry El Niño years; and
- the frequency, severity, and/or duration of extreme weather events such as drought and high intensity rainfall, and weather-related events such as flooding, and coastal storm surges.

*3b) Climate Impacts Group, University of Washington*

On average, global climate system models project a future rate of warming of roughly 0.9ºF (0.5ºC) per decade for the PNW (Table 1). This is substantially more than the 0.4ºF (0.2ºC) increase per decade observed during the last half of the 20$^{th}$ century.

**Table 1.** Changes in PNW climate from eight climate models for the 2020s and 2040s (from the 1990s)

| | **Temperature change** | **Precipitation Change** | |
|---|---|---|---|
| | Annual | October – March | April – September |
| **2020s** | | | |
| Low | + 0.9ºF (0.5ºC) | +2% | - 4% |
| Average | + 2.7ºF (1.5ºC) | +8% | +4% |
| High | + 4.7ºF (2.6ºC) | +18% | +14% |
| **2040s** | | | |
| Low | + 2.7ºF (1.5ºC) | -2% | - 7% |
| Average | + 4.1ºF (2.3ºC) | +9% | +2 % |
| High | + 5.8ºF (3.2ºC) | +22% | +9% |

The projections for PNW climate are derived from eight coupled global-atmosphere climate models: CCSR, CGCM1, CSIRO, ECHAM4/OPYC, GFDL, HadCM2, HadCM3, and NCAR PCM3 (Mote *et al*. 2003). The models assume an annual increase in equivalent carbon dioxide concentrations of approximately 1% per year. Changes are benchmarked from the average for the decade of the 1990s.

Additional details from the models about future changes in PNW climate include the following:

- Warming rates are projected to be similar in winter and summer.
- Winter precipitation increases in all models.
- Summer precipitation is projected to remain low.
- Projected decade-to-decade variability in temperature is relatively small compared with the observed (let alone projected) rise in temperature.
- Projected decade-to-decade variability in precipitation is larger than the trends for both observed (20$^{th}$ century) and simulated (20$^{th}$ and 21$^{st}$ century).

- Because many key aspects of climate (e.g., windstorms, heat waves) are not well simulated by models, we decline to speculate about how they may change in the future. However, droughts may become more common because even with the same precipitation, higher temperatures increase evaporation rates, reducing water available for streams and vegetation.
- Changes in the behaviour of climate patterns like the El Niño/Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the Arctic Oscillation (AO) are projected by most models, but the observed behaviour of these patterns is not well represented in models. As a result, there is no conclusive evidence as to how climate patterns such as ENSO, PDO, and the AO may change in the future.
- Contrasts within the region. Simulations with a regional model (a climate model with very high spatial resolution) suggest a few important respects in which climate change may differ from the projections of the global models. For example, warming may proceed more quickly at higher elevations than in the lowlands owing to snow-albedo feedback: when snow cover is reduced, it enhances absorption of solar radiation and warms the surface more (Leung *et al*. 2003).

*Reports referenced in the information from the University of Washington's Climate Impacts Group can be found at: www.cses.washington.edu/cig/* .

## Appendix Seven: Recommended Web Sites

*Print and web references are included in summaries for each presenter. The following additional references will be of interest to resource managers with an interest in British Columbia's changing climate. Addresses for each web site were active as of July 2005.*

**BC Climate Exchange**
http://bcclimateexchange.ca/index.php
The BC Climate Exchange provides a connection to people, resources, and tools for education, outreach, and training on climate change, its impacts, and solutions. They also offer a list serv for announcements.

**B.C. Ministry of Environment – Climate Change Home Page**
http://wlapwww.gov.bc.ca/air/index.html
Includes indicators of Climate Change in British Columbia, emissions information, and much more.

**B.C. Ministry of Environment – Indicators of Climate Change 2002**
http://wlapwww.gov.bc.ca/air/climate/indicat/index.html
Excellent information on past climate change in British Columbia.

**B.C. Ministry of Environment –Weather, Climate, and the Future: BC's Plan**
http://wlapwww.gov.bc.ca/air/climate/index.html
This site describes British Columbia's approach as it works with the federal government, industry, local government, and individuals to address climate change.

**Environment Canada—Adaptation and Impacts Research Group**
www.msc-smc.ec.gc.ca/airg/index_e.cfm
The Adaptation and Impacts Research Group conducts research on the impacts of weather, climate, and air quality on human health and safety, economic prosperity, and environmental quality. The web site includes links to past and on-going projects in British Columbia as well as other parts of Canada.

**Government of Canada—Climate Change Web Site**
http://climatechange.gc.ca/english/index.shtml
This is the main portal for federal government information on climate change, reducing greenhouse gas emissions, and federal action on climate change.

**Intergovernmental Panel on Climate Change**
www.ipcc.ch/
The Intergovernmental Panel on Climate Change assesses scientific, technical and socio-economic information relevant for the understanding of climate change, its potential impacts, and options for adaptation and mitigation.

**Natural Resources Canada – Canadian Climate Impacts and Adaptation Research Network (C-CIARN)**
www.c-ciarn.ca/ (National web site)
http://c-ciarn-bc.ires.ubc.ca (British Columbia web site
http://forest.c-ciarn.ca/ (Forests sector web site)
The goal of C-CIARN is "to build a network of researchers and stakeholders that will help to develop credible information on the impacts of climate change in Canada and help to identify adaptation options in order to anticipate and prepare for the changes that are expected during the 21st century." C-CIARN is a part of Natural Resources Canada. It has both regional and sectoral divisions. All are accessible from the national site.

**Natural Resources Canada—Climate Change Impacts and Adaptation Program**
http://climatechange.nrcan.gc.ca/english/index.asp
Describes research and activities to improve our knowledge of Canada's vulnerability to climate change, to better assess the risks and benefits posed by climate change and to build the foundation upon which appropriate decisions on adaptation can be made.

**Natural Resources Canada—Climate Impacts and Adaptation Project Database**
www.adaptation.nrcan.gc.ca/home2_e.asp?CaID=9&PgID=23
Through a competitive proposal process, the Climate Impacts and Adaptation Research Program supports cost-shared research to address gaps in our knowledge of Canada's vulnerability to climate change and to provide information for adaptation decisionmaking. This project database provides information on the research funded. Where the project is completed, a link is available to the final project report.

**Natural Resources Canada—Pacific Forestry Centre, Canadian Forest Service**
www.pfc.cfs.nrcan.gc.ca/index_e.html
The Pacific Forestry Centre has a number of initiatives related to climate change, mountain pine beetle, and other forestry research issues.

**University of British Columbia—Centre for Forest Gene Conservation**
http://genetics.forestry.ubc.ca
http://genetics.forestry.ubc.ca/hamann/
This is the home page of Andreas Hamann, at the University of British Columbia's Centre for Forest Gene Conservation.

**University of Victoria—Canadian Institute for Climate Studies**
www.cics.uvic.ca
CICS's mission is to further the understanding of the climate system, its variability, and potential for change, and to further the application of that understanding to decision making in both the public and private sectors. Includes scenarios and more.

**University of Washington Climate Impacts Group**
www.cses.washington.edu/cig/
CIG is an interdisciplinary research group studying the impacts of natural climate variability and global climate change ("global warming") on the United States' Pacific Northwest

(PNW). Through research and interaction with regional stakeholders, the CIG works to increase the resilience of the Pacific Northwest to fluctuations in climate. The CIG's research focuses on four key sectors of the PNW environment: water resources, aquatic ecosystems (including the Columbia River system), forests, and coasts.

In 2003, the Columbia Mountains Institute invited Philip Mote and Alan Hamlet from this group to make presentations at the “Climate Change in the Columbia Basin” workshop. Their PowerPoint presentations are available at:
http://ftp.hydro.washington.edu/pub/hamleaf/bc_climate_change/